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# AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD LECTURE SERIES No.125

# Human Factors Aspects of Aircraft Accidents







NORTH ATLANTIC TREATY ORGANIZATION

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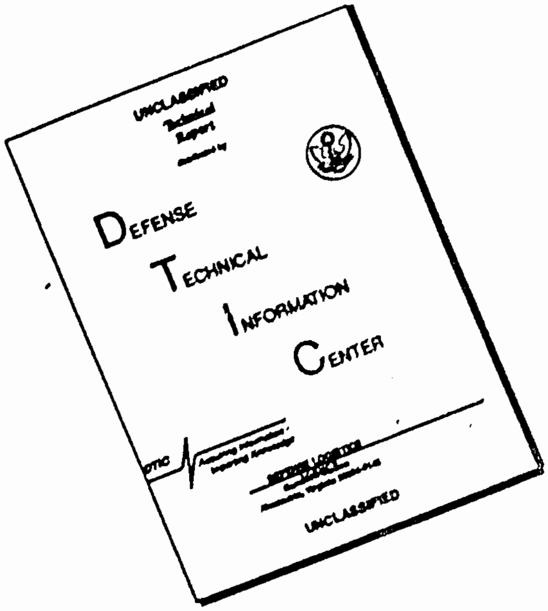


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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Lecture Series No.125

# HUMAN FACTORS ASPECTS OF AIRCRAFT ACCIDENTS

**The material in this publication was assembled to support a Lecture Series under the sponsorship of the Aerospace Medical Panel and the Consultant and Exchange Programme of AGARD, presented on 4–5 November 1982 in Lisbon, Portugal, 8–9 November 1982 in Ankara, Turkey and 11–12 November 1982 in Athens, Greece.**

## THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

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Due to other commitments, Dr B.O.Hartman was unable to participate in the presentations of the Series in Lisbon, Ankara and Athens. The three Meetings were actually chaired by:

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## CONTENTS

# AN OVERVIEW OF HUMAN FACTORS IN AIRCRAFT ACCIDENTS AND INVESTIGATIVE TECHNIQUES

by

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BACKGROUND: Late in 1979, NATO asked AGARD to increase its advisory support to the NATO Southern Flank Nations (Turkey, Greece, Portugal). The AGARD National Delegates Board directed the panels, through AGARD Headquarters, to make proposals for this enhanced support. The Aerospace Medical Panel proposed approximately a dozen technical subjects appropriate to the medical aspect of current military aviation, with special, but not exclusive, emphasis on the fighter aircraft environment. The panel also suggested that these topics could be presented as consultant's visits, tutorials of various sorts, or lecture series, the choice being left to the Southern Flank Nations.

At the 1980 Spring meeting of the medical panel, members from the Southern Flank Nations chose four topics on which they desired technical support. The topic, "Human Factors Asepcts of Aircraft Accidents," was one. The medical panel decided that a lecture series would be appropriate, and made that recommendation to the National Board of Delegates. The board approved the proposal in September 1980, for the 1982 program.

At the 1980 Fall meeting of the medical panel, the scope of the lecture series was changed, in accordance with the wishes of three Southern Flank Nations. These nations requested a less specialized, more broad-based set of lectures, covering a larger spectrum of technical areas and investigative procedures, rather than a focus on human factors specifically. The following paragraphs describe this broader scope, although the title, "Human Factors Aspects of Aircraft Accidents," has been retained.

GENERAL STRUCTURE: The lecture series has been divided into three sessions to be covered in two days. The lectures on the first day (Session I) provide a general review on the technical background relevant to accident factors and concerns. They start with a status report on the aircraft accident problem in the NATO community, followed by lectures on engineering considerations, aviation medicine and physiology aspects, human factors aspects, and pathology. There are two sessions on the second day. Session II addresses investigative techniques, and includes lectures on engineering, life support systems/ restraint/ejection, and the flight surgeon's investigation. The flight surgeon's lecture is the one where all of the earlier lectures will come into an integrated focus, and therefore will be a two-hour lecture, in contrast to the others which are generally one hour long. Session III (which is short) contains one lecture on an aspect not addressed elsewhere, the medical-legal aspects. The remainder of the session is devoted to a round table discussion, in which the audience is invited to participate. All lecturers will allow a few minutes at the end of their presentations for questions from you, the audience.

The audience should keep in mind that this lecture series is sponsored by the AGARD Medical Panel, and therefore appropriately emphasizes the medical aspects of aircraft accidents. We recognize that this audience is a mixture of fully qualified flight surgeons, medical officers with general knowledge of the medical issues significant in the aviation environment, and operational officers with limited understanding of medical and physiologic issues, but with a superb knowledge of the operational environment. Such a mixed audience presents a real challenge to your lecturers during their oral presentations, requiring them to walk a narrow line between being too basic for the most knowledgeable of the audience and too advanced for the less knowledgeable. The written manuscripts offer you, the audience, the opportunity to acquire more advanced levels of knowledge, since the manuscripts are typically twice as long (or more) as the spoken text. Each of you received (this morning) a book containing the complete manuscripts for every lecture. You may at times wish, therefore, to formulate questions from the floor by referring to a specific page in the book, either during the discussions after each lecture or during the round table discussion at the end of the second day.

SCOPE FOR EACH LECTURE: The following short descriptions of each lecture are provided to give you a general idea of the lecture series director's concept of the scope of each presentation/manuscript. Lecturers are not limited to this description; in particular, the lectures may vary from the manuscripts as each lecturer senses the needs and interests of this audience.

"Overview." This presentation by the lecture series director will last about 30 minutes. I will cover what we are, who we are, and why we are here.

"Current Status and Significant Concerns." The title describes the lecture. The lecture will set the stage for the lecture series. It will include some history (particularly the past five years), the current situation functionally and statistically, the more significant effects of the newest aircraft in the inventory, the more significant aspects of the operational environment, and the important features of the European environment (weather, seasons, major air traffic areas, air traffic control issues). This lecturer has the option of including civil as well as military aviation. (one hour)

"Influence of Handling Qualities, Crash Worthiness, and Other Engineering Factors." This lecturer is our primary engineer. The lecturer will discuss the general engineering in principles of aircraft handling qualities and crash worthiness as they relate to safety and survivability, military specifications framework for including safety, and gaps in engineering design technology. The focus will be on current and next generation military aircraft. This lecture will provide an information base for a later lecture on investigative techniques. (one hour)

"Medical/Physiologic Factors." This will be a general review of aviation medicine and aviation physiology, with a specific focus on those aspects which relate to safety and accidents. It will include environmental stressors, physiologic effects of altitude, barotrauma, the acceleration environment and effects, disorientation and illusions, visual function and problems, noise/vibration/thermal problems, stress and fatigue, motion sickness, drugs, acute causes for grounding, and causes of sudden incapacitation. It will not cover medical standards and selection, annual physical examinations, preventive medicine, nor

the administrative aspects of aviation medicine. The lecture will be limited to military aviation and to active aircrew members (not passengers), and will provide an information base for a later lecture on investigative techniques. (one hour)

"Human Factors." This lecture will be a general review of the principles and practice of human factors (human factors engineering, human engineering, aviation psychology are sometimes used as synonyms), with a specific focus on those aspects which relate to safety and accidents. Topics to be covered will include display and control design, information presentation and processing, cockpit workload, man-machine interface, man-mission interface, cockpit layout, anthropometric factors, psychological and/or personality factors, and any special issues related to design for safety. The lecture will be limited to military aviation, focus on fighter aircraft, and provide an information base for a later lecture on investigative techniques. (one hour)

"Pathology Aspects." This will be a general review of the principles and practice of aviation pathology as it applies to aircraft accidents, both civil and military, and for both aircrew and passengers. The topics covered will include, but are not limited to, the post-mortem examination and autopsy, analysis of body tissue and fluids, the contributions to the accident of pre-existing disease, environmental and traumatic factors, drugs, ingestion, routine and special toxicology, and field procedures required to ensure an adequate pathology study. The lecture is intended to provide an information base for a later lecture on medical-legal aspects. (45 minutes)

"Engineering Investigation." This lecture is the first to be devoted entirely to investigative techniques and procedures. Topics to be covered will include the on-scene investigation and documentation, the removal of the aircraft and follow-on analyses, the selection of systems and subsystems requiring study, the selection of appropriate consultants and experts, use of simulation and other analytic alternatives, and longer range system studies. The focus is on "how to" and "look for." (one hour)

"Life Support Systems/Restraint Systems/Ejection Investigation." This lecture will start with a listing and descriptions of the hardware involved in life support/restraint/ejection, then identify the qualifications required of an investigator and the facilities and support he will require. The lecture then turns to investigative techniques on-scene and the required documentation, the follow-on studies and required documentation, and (where appropriate) the longer range system studies. The focus will be on fighter aircraft. The amphasis will be on "how to" and "look for." (one hour)

"Flight Surgeon's Investigation." All of the earlier lectures come together in this "how to" and "look for" lecture. Topics to be covered will include, but are not limited to, pre-accident planning and organization, the role of the flight surgeon on the investigation board, aircrew/passenger rescue and management, the on-scene investigation, recovery and management of remains, follow-on studies, investigative tools and techniques, post-mortem, autopsies, pathology/toxicology studies, retrospective medical records review, psychological and human factors studies, integration of data from the medical and related investigations, and documentation and identification of cause factors. The lecture will deal primarily, but not exclusively, with fighter accidents. (two hours)

"Medical-Legal Considerations." This "last but not least" lecture has been placed last in the series because, in some ways, medical-legal aspects are a "stand-alone" subject--the downstream consequences of an accident--the entry into the accident arena of new players from the legal profession, among others. The lecture will address principles, practices, and problems in the medical-legal arena, and identify from the earlier "how to" lectures those procedures and products which result in significant downstream problems if poorly executed and documented.

At this point, I would like to address, in a more technical fashion, some of the areas to be covered in the lectures. As a member of the staff of the Clinical Sciences Division of the USAF School of Aerospace Medicine, I am naturally interested in medical aspects of aircraft accident causation. Three papers in the journal of the Aerospace Medical Association (the journal is titled Aviation, Space and Environmental Medicine) caught my attention as I began preparation for this lecture series. I will report on them briefly. The first[1] dealt with the epidemiology of general (civil) aviation accidents in the year 1974. There were approximately 5000 accidents for which there were adequate records on the pilot. I will not cover every analysis in that paper, but some seem particularly appropriate to your interests. First of all, high exposure resulted in higher accident rates for even the professional pilot, excluding the air line pilots. Stated another way, the more you fly, the more likely you are to have an accident, not just in terms of simple frequency, but also in terms of rate. Second, civil aviation data suggests experience (total flying time) is an asset, up to a point. At some point, the experienced pilot can become overconfident and less vigilant, and perhaps less disciplined in preflight planning and in-flight routines. Similar factors may be operating with recent exposure, which shows a considerably higher rate than that seen when there is a substantial lapse of time between flights. Rates increase with age, a relationship frequently described, but the relationship is complex. I invite you to read the paper; I was struck by the fact that young pilots with high exposure rates and high recent exposure are the most vulnerable. For civil aviation, the peak months for accidents in the United States are April through September, the best months for flying, and, therefore, the months of increased aviation activity and exposure. Most (85 per cent) accidents occur between 9 AM and 9 PM, again the period of increased activity and, therefore, of exposure. Fatigue is frequently highlighted as a cause factor. However, 55 per cent of the accident-involved pilots had flown less than one hour in the past 24; more serious accidents occurred in the first hour of flight; 48 percent of the fatal accidents occurred in the first half-hour. I am not prepared to state that fatigue was not a factor, since no data on preceding non-flying activity were presented, but it seems safe to say fatigue caused by long duration flights does not appear to be a factor in civil aviation. Finally, 42 per cent had undergone a medical examination within the previous six months and 75 per cent within the previous year. I am tempted to say that this indicates that pre-existing disease is not an important factor in civil aviation accidents, but data in this paper do not provide sufficient support for that statement. However, two more recent papers deal with that very issue. Underwood Ground[2] reports on experience with pre-existing disease in aircrew involved in fatal accidents. The kinds and rates are similar to the population as a whole. This author adds that it is difficult to establish the role of pre-

existing disease for many reasons, and that the medical investigator will at best be working with circumstantial evidence, almost without exception. Voge[3] reports on pre-existing disease in the U.S. Navy. This author describes the Navy aircrew population as healthy and undergoing careful medical examinations frequently. She reports on a review of over 2000 medical records on accident-involved aircrew where there was pre-existing disease and concludes most would not be incapacitating but might contribute to "pilot error" or "undetermined" causes. This author also comments on the difficulty of obtaining definitive data.

Another major area is human factors. The USAF School of Aerospace Medicine supported a contract ending in 1980 in which an independent examination of accidents with human factors elements was performed. (This was only part of a larger study.) The contractir[4] analyzed 70 USAF accidents from the years 1977-1978, using his own coding system. He identified six major pilot factors and calculated costs, as follows:

| Factor | # Mishaps | Per Cent | Total Cost ($M) |
|---|---|---|---|
| Channelized attention | 32 | 46 | 146.3 |
| Distraction | 26 | 37 | 107.5 |
| Disorientation/vertigo | 22 | 31 | 72.4 |
| Excessive motivation | 14 | 20 | 54.0 |
| Over-confidence | 13 | 19 | 47.7 |
| Stress | 13 | 19 | 26.8 |

This listing provides a framework for resource allocation were one to launch a research program on human factors causes in aircraft accidents--but that would be an intimidating initiative to say the least. More relevant to the lecture series, it is a shopping list of factors to be investigated by the human factors specialists on an accident investigation board. The contractor also examined antecedent conditions in relation to the above factors, using USAF coding and then his own coding, with the following results:

| Antecedent Factor | Pilot Factor | Correlation |
|---|---|---|
| | USAF Coding | |
| Air-to-air | Channelized attention | .37 |
| Air-to-ground | Channelized attention | .29 |
| Total 1st pilot hours | Distraction | -.30 |
| Clear weather | Disorientation/vertigo | .70 |
| Physical condition | Disorientation/vertigo | .38 |
| | BDM Coding | |
| Air-to-ground | Channelized attention | .36 |
| Low-level navigation | Channelized attention | .20 |
| Air-to-ground | Disorientation/vertigo | .24 |
| Air-to-ground | Excessive motivation | .30 |
| Hours slept previous 24 | Apprehension | .22 |
| Hours slept previous 24 | Visual illusion | .29 |

These analyses also provide guidance to the human factors investigator.

Santilli[5], in a technical report published in 1980, takes a somewhat different approach to human factors in aircraft accidents. He uses a man-environment concept and focuses his analysis on the critical interfaces. He analyzed USAF mishaps during an 18-month period starting in January 1977. Four major environmental variables emerge from his analysis: weather, training deficiencies, supervisory deficiencies, and special missions. There were also four major aircrew variables: situation disorientation, task proficiency, concentration deficiencies, and judgement errors. It is the co-occurrence of environmental and man variables that is the major contributor to mishaps. This is an important concept--the conjoint or simultaneous combinations of variables which turn an innocuous situation into an accident. In Santilli's data, man (aircrew) variables were most significant 72 per cent of the time. This highlights the role of human factors in aircraft accidents.

As an aside, Santilli and I jointly developed the concepts of anomalies of attention and anomalies of orientation as a convenient way of clustering several significant elements of human factors. Santilli's list for anomalies of attention includes channelized attention, distraction (internal and external), cognitive task saturation, inattention, habitation, negative transfer, and fascination. My list for anomalies of orientation includes disorientation with regard to three-dimensional space (classical spatial disorientation), with regard to where you are in the scenario phase (in-flight sequence), with regard to the overall scenario, in relation to the total combat environment, in relation to the ground/obstacles, and geographically. Such "clustering" concepts may be useful.

The USAF master analyst of aircraft accidents is Dr. Anchard Zeller. In his most recent paper[6], he predicts where the USAF is going in terms of accidents on the basis of experience during the 1970's. He makes many points; I have chosen only a few. The human factors problems of the 1980's will be: (1) perception and decision-making during emergencies; (2) in-flight sequencies rather than take-off and landing; and (3) military aircraft collisions with civil aircraft. These are preventable by use of well-established principles of accident prevention, better selection and training, and hardware improvements. For military aviation in particular, "event" proficiency (e.g., strafing, missile launches, low-level, high-speed attacks) is becoming important. Zeller emphasizes the need for more training on simulators, part-task trainers and training aids, and perhaps enhanced visual screening to augment the time-honored visual acuity measures. The greater increase in training realism carries with it the potential for an increase in the mishap rate. The most common pilot errors are: (a) failure to follow instructions; (b) improper in-flight planning; (c) distraction; and (d) faulty division of attention. The USAF continues to work on ejection fatalities--for the most part these are the result of failure to eject soon enough; however,

increased low-level operations sometimes force the aircrew to eject outside the ejection envelope. Within the USAF, there is renewed interest in physiologic and neuromuscular tolerances and capabilities. (The USAF is currently considering establishing strength standards for screening of applicants for aircrew training (Undergraduate Pilot Training). Zeller emphasizes the importance of recognizing emergencies early and acting quickly.

Before closing this brief review of recent papers, I want to call to the attention of this audience a recent and provocative article in the USAF Flying Safety magazine. Carson[7] addresses the ejection decision processes in terms of a phenomenon he calls "temporal distortion." The well-recognized physiologic "alarm reaction" to a sudden emergency creates a state of arousal. There is increasing anecdotal evidence of "a temporary false perception which shows the apparent passage of time." Carson suggests this may account for some late decisions to eject--that it may in fact be a principal cause. His solution: educate pilots about the phenomenon, stressing that "under acute stress you cannot trust your sense of time." The School of Aerospace Medicine is currently examining ways to investigate this phenomenon, validate it, and quantify it.

This concludes my introduction and overview to AGARD Lecture Series #125, "Human Factors Aspects of Aircraft Accidents." Let us turn to the task at hand with our first lecturer.

## REFERENCES

1. Booze, C. F. Epidemiologic investigation of occupation, age, and exposure in general aviation accidents. Aviation, Space and Environmental Medicine 48:1081-1091, 1977.

2. Underwood Ground, K. E. Occurrence of pre-existing disease in aircrew killed in flying accidents. Aviation, Space and Environmental Medicine 52:672-676, 1981.

3. Voge, V. N. Role of pre-existing disease in the causation of naval aircraft mishaps. Aviation, Space and Environmental Medicine 52:677-682, 1981.

4. Contract report, "Definition of investigative areas for human factors aspects of aircraft accidents." BDM/W-79-733-TR, February 1980, BDM Corp., 7915 Jones Branch Ave., McLean VA (22102), USA.

5. Santilli, S. R. "Critical interfaces between environment and organism in class A mishaps: A retrospective analysis." SAM-TR-80-3, June 1980, USAF School of Aerospace Medicine, Brooks Air Force Base TX (78235), USA.

6. Zeller, A. F. Human error in the seventies--reviewed and projected through the eighties. Aviation, Space and Environmental Medicine 52:241-246, 1981.

7. Carson, D. M. Temporal distortions and the ejection decision. Flying Safety 38:9ff, March 1982.

ASPECTS DES FACTEURS HUMAINS
DANS LES ACCIDENTS D'AVIATION

STATUT ACTUEL ET SOUCIS SIGNIFICATIFS
(M. VIGIER)

**Résumé**

Dans la chaîne classique des éléments générateurs d'un accident d'aviation, l'enquêteur est fréquemment conduit à prendre en considération le facteur humain.

A l'intérieur du contexte européen, réunissant des caractéristiques particulières plus ou moins propices à la sécurité aérienne, il est intéressant d'examiner quelques aspects statistiques et de tenter d'évaluer l'importance de ce facteur par rapport à l'ensemble des facteurs causals retenus. Le pourcentage ainsi mis en évidence varie peu au cours des années et reste assez identique quelle que soit la catégorie d'activité aéronautique : il dépasse très probablement le taux de 60 %.

Il n'est pas facile d'appréhender correctement ce facteur qui couvre un champ immense. Sur les deux volets des personnels au sol et des navigants sont esquissés certains des principaux axes de recherche. Toutefois, si l'enquêteur peut généralement mettre en évidence les implications de l'erreur humaine dans le déroulement de l'accident, les raisons profondes échappent souvent et mériteraient les soins des spécialistes.

-=-=-=-=-=-=-=-=-

Un de nos confrères enquêteurs du National Transportation Safety Board Jerry BRUGGINK a, il y a quelque temps, émis l'opinion que "les accidents sont nécessaires pour maintenir un certain taux de sécurité".

Pour paradoxal que puisse paraitre un tel point de vue, il est cependant très évident que des enquêtes bien conduites sont susceptibles de fournir des données dont l'étude pourra contribuer largement à l'ensemble des mesures et moyens de prévention.

Une autre citation, émanant d'un Wing Commander de la Royal Air Force : "l'homme est d'un entretien facile et sa fabrication n'exige pas une adresse excessive", si elle peut être médicalement controversée dans sa première partie, nous permet, cependant, de penser qu'en dépit des progrès techniques et de la multiplicité des boites noires, les facteurs économiques exigeront encore beaucoup de temps avant que la part de l'intervention humaine, au moins dans la conception, le contrôle, l'entretien ou la mise en oeuvre des matériels, soit réduite à un rôle quasi inexistant.

Un accident d'aviation, plus encore peut-être que tout autre, est rarement le résultat d'une cause unique entrainant des conséquences imparables mais découle, le plus souvent, de l'accumulation d'une série de facteurs dont chacun, pris isolément, pourrait ne pas forcément comporter de risques graves. Dans cette chaîne classique des éléments générateurs de la catastrophe aérienne, l'enquêteur est fréquemment conduit, et il est peu probable que cela change avant longtemps, à prendre en considération ce qu'il est convenu d'appeler les facteurs humains.

Il est probablement significatif que le premier accident aérien porté à la mémoire des hommes, celui d'Icare, ait précisément mis en cause les facteurs humains ...

Sur un plan, hélas moins allégorique, l'expérience acquise au cours des dernières décades par l'ensemble des enquêteurs d'accidents d'aviation dans le monde, leur a appris que ces facteurs continuaient de jouer un rôle prépondérant, rôle qu'il peut être intéressant d'essayer de mieux identifier dans le contexte européen qui est le nôtre.

Avant de tenter une évaluation statistique de leur importance et de souligner quelques uns de leurs aspects principaux, il convient de rappeler certaines des caractéristiques de l'environnement général et opérationnel particulier à l'Europe.

Compte tenu de la nécessité de disposer de sources aussi fiables que possible, le cadre de cette étude a été intentionnellement limité aux données intéressant les vingt deux Etats membres de la Commission Européenne de l'Aviation Civile :

Autriche, Belgique, Chypre, Danemark, Espagne, Finlande, France, Grèce, Hollande, Irlande, Islande, Italie, Luxembourg, Malte, Norvège, Portugal, République Fédérale Allemande, Royaume Uni, Suède, Suisse, Turquie, Yougoslavie.

La zone géographique ainsi couverte représente près de quatre millions six cent cinquante milles kilomètres carrés et comporte plus de quatre cent dix millions d'habitants.

Un tel ensemble montre de nombreuses disparités mais aussi des convergences qui, les unes et les autres, ne sont pas sans influer plus ou moins largement sur le déroulement des activités aéronautiques et, aussi, sur le comportement des facteurs humains "nationaux".

Parmi les disparités, certaines sont évidentes et résultent du simple examen des chiffres d'autres sont quelque peu plus subtiles :

- les vingt deux Etats étudiés constituent une mosaïque de territoires nationaux de superficies très inégales : rapport de 1 à 2500 entre le plus petit et le plus étendu, surface moyenne théorique de l'ordre de 200.000 km2, largement dépassée par 7 Etats et très loin d'être atteinte par plus de 10 d'entre eux, densité de population variant au moins du simple au quadruple.

- cinq de ces Etats ne font pas directement partie du continent mais sont insulaires, l'un d'entre eux à des milliers de kilomètres de l'Europe proprement dite.
Un autre Etat est au confluent du Moyen-Orient et de l'Europe.

- En dépit d'une langue aéronautique, l'anglais, théoriquement commune, vingt autres langages au moins sont des langues maternelles normalement utilisées.

- les législations nationales peuvent différer très notablement : le code Napoléon dont les règles strictes continuent avec quelques variantes, a être appliquées dans plus du tiers des Etats reste infiniment moins flexible que la législation d'inspiration anglo-saxonne.

- les conditions météorologiques varient très largement du Nord au Sud de l'Europe et l'influence des saisons s'y révèle très sensible.

La diapositive n°1 présente quelques caractéristiques générales :

- Europe de l'Est : hivers très froids
- Europe Centrale : hivers froids, étés chauds
  pluies le plus souvent en été
- Europe Nord-Ouest : hivers doux, étés frais
  air humide, nuages fréquents
  pluies principalement en automne
- Europe Méditerranéenne : étés chauds, ensoleillement abondant
  hivers très doux, pluies essentiellement en automne et au printemps

Les diapositives 2, 3, 4 et 5 donnent une répartition moyenne des températures rencontrées aux environs de 3 000m, au fur et à mesure des saisons :

- en janvier, du Sud au Nord, toutes températures négatives de -2°C à -16°C
- en avril, toujours du Sud au Nord, de +2°C à -14°C
- en juillet, de +10°C à -4°C, l'isotherme 0° est remonté assez haut vers le Nord, au Nord de l'Angleterre et de l'Allemagne, au Sud des pays scandinaves
- en octobre, de +4°C à -10°C, les températures négatives recouvrent à nouveau les 3/4 de l'Europe.

De façon plus précise, il est intéressant d'examiner quelques autres dispositives, également préparées grace aux renseignements fournies par la météorologie nationale française, et portant des indications climatiques pour certains aérodromes situés en différents points de l'Europe. Ces indications ne sont cependant valables que pour chacun des aérodromes concernés et ne sont donc pas forcément représentatives de la région où ils sont situés.

Diapositive n°6 Les courbes de températures moyennes sont très régulières. Elles donnent peu d'indications imprévues, il faut s'attendre à des gelées persistantes dans les pays nordiques en hiver et à des températures supérieures à 25° dans le Sud de l'Europe en été. A Stockholm -32°C en janvier - Athènes +44° C en août.

Diapositive n°7 Outre les gelées persistantes en janvier/février à Oslo, Stockholm ou Munich, on constate aussi de nombreuses gelées hivernales des régions continentales du Sud Europe (Madrid, Belgrade, Ankara), on a omis volontairement Lisbonne, Barcelone, Athènes où les gelées sont rares.

Diapositive n°8 Deux pays se distinguent par la fréquence des vents forts en hiver (40% de vent > 17 kt) ainsi que le nord de l'Irlande. Dans les autres régions balayées par les perturbations atlantiques d'ouest cette fréquence est modérée avec des maxima en février (Paris-Londres) et octobre (Edimbourg). A noter l'influence des vents locaux (Mistral à Marseille) et une pointe importante au mois de juillet à Lisbonne. Dans l'ensemble, le sud de l'Europe est cependant moins perturbé par le vent que le nord.

Diapositive n°9 Le maximum des jours d'orage a lieu en général en été, sauf à Edimbourg (2 pointes au printemps et en automne) ou à Rome (orages répartie toute l'année). L'influence orographique donne un nombre de jours d'orage considérables en plein été (10 jours par mois à Milan, Belgrade). Dans les pays très froids (Islande) ou en hiver dans l'Europe du Nord, il n'y a pratiquement pas d'orage. Par contre dans les régions chaudes, des orages ont lieu en hiver d'où les maxima de précipitations à cette époque.

Diapositive n°10 Keflavik mis à part (14 jours par mois en hiver), sur la Scandinavie et le Nord Est de l'Europe, le nombre de jours de précipitations modérés subit un maximum très marqué en été (Copenhague, Munich); dans les régions côtières, le diagramme est plus étalé. Au Sud dans les pays méditerranéens les maxima ont lieu pendant les saisons froides, l'été y est marqué par la sécherssse (Marseille, Rome).

Diapositive n°11 Conditions d'atterrissage médiocres. Les plus mauvaises conditions se présentent en hiver et automne avec des maxima en février et octobre/novembre. Deux aérodromes se distinguent Milan (92 % en décembre) tandis qu'à Athènes les bonnes conditions règnent toute l'année. Il n'y a cependant pas de nettes différences entre le Nord et le Sud de l'Europe par exemple, les conditions sont plus mauvaises en hiver à Belgrade ou même à Madrid qu'à Keflavik.

Diapositive n°12 Les régions situées près de la mer ont un maximum de brouillard très prononcé en hiver (Hambourg, Londres, Paris). Sur les aérodromes situés plus à l'intérieur, le maximum se situe au printemps ou en été ( Belgrade).
Absence de brouillard à Athènes. Faible fréquence à Marseille.

Les diapositives n° 1 à 12 n'ont pu être reproduites en raison de leur format. L'essentiel des indications qu'elles présentent figure dans le texte de la conférence.

Mais, parallèlement à ces disparités, le contexte européen présente également de nombreux point de convergences :

-L'ancienneté de la civilisation en Europe, les brassages dus aux mouvements de population, qu'ils aient été le fait des conquérants, des pélerins ou des croisés, des marchands ou des voyageurs plus ou moins volontaires, ont conduit à une certaine unicité des cultures. Tout en gardant, au moins partiellement, leurs caractères propres, les européens ont fini par partager un certain fond commun qui, avec des variantes parfois encore marquées, a abouti pour les personnels à une bonne éducation de base et un niveau de compétence technique assez élevé.

- En ce qui concerne le matériel au sol et plus particulièrement le converture aéronautique (centres de contrôles, aéroports et leurs installations, aides à la navigation, à l'approche et l'atterrissage) la technicité et la densité des moyens en place est évidente et résulte tout à la fois d'une technologie évoluée de longue date et de la nécessité d'assurer correctement un trafic aérien très important (à titre indicatif - diapositive 13 - il est intéressant de constater l'ampleur et la répartition des seuls vingt cinq premiers courants de trafic internationaux européens de passagers - quinze millions cinq cent mille en 1978).

- Si l'on examine, au sein des 22 Etats de la C.E.A.C. à la date du 1er janvier 1981, la flotte d'appareils de transport public de masse supérieure à 9.000 kg (20.000 lbs), on constate (selon les données fournies par l'Institut du Transport Aérien) qu'il existe plus de 80 compagnies européennes exploitant environ 1.600 avions de cette catégorie, soit (selon les statistiques de l'O.A.C.I., visant 144 Etats, Chine et U.R.S.S. exceptées) près de 20% de la flotte mondiale dans ce secteur. Il est encore plus intéressant de noter que cet ensemble dépasse le cinquième des quadriréacteurs mondiaux, 10 % des triréacteurs et atteint près de 30 % du total des biréacteurs et près de 20 % des turbopropulseurs. Cette flotte européenne est aussi une flotte moderne qui ne comporte que moins de 2 % d'avions à moteurs à pistons contre 16 % de turbopropulseurs et 82 % de réacteurs. (Pour ne citer que quelques une des principaux types d'avions en service (1er janvier 1981) : 14 Concorde, 103 Boeing 747, 77 DC 10, 78 DC 8, 115 Boeing 707, 47 Airbus A300, 160 Boeing 727, 160 Boeing 737, 207 DC 9 ainsi que 75 BAC 111 et 80 SE 210).)
La nature même de la composition d'une telle flotte, finalement assez homogène, implique inévitablement un haut niveau des conditions d'entretien et d'exploitation partagé entre l'ensemble des éléments de la mosaïque européenne.

L'aviation générale de ces vingt deux états représente également un chiffre important de l'ordre, toujours début 1981, de 26.000 avions et 14.000 planeurs. Il n'existe plus, malheureusement, de données récentes permettant de mieux décrire les avions de cette catégorie d'activité, on peut seulement estimer que 90 % sont des monoplans, un train tricycle équipant plus de 60 % d'entre eux et il semble qu'un maximum de 15 à 20 % de cette flotte soit de conception ou de fabrication ancienne. Il reste que là encore un grand nombre de facteurs communs se retrouveront dans les appareils, leur entretien et leur exploitation.

- Des liens encore plus étroits tendent à améliorer ou à standardiser l'activité aéronautique européenne à la suite d'accords inter Etats, inter constructeurs et inter compagnie. Nous ne citerons que pour mémoire le rôle de l'OTAN dans l'aviation militaire ou celui d'Eurocontrôle dans la surveillance de l'espace supérieur de vol, mais il faut encore rappeler la construction en coopération par de nombreux états européens de divers types d'avions ou d'hélicoptères parmi les plus connus : Transall, Concorde, Tornado, Jaguar, Alphajet, Airbus ...

Sur le plan des compagnies aériennes, il faut essentiellement noter l'existence des groupes KSSU et ATLAS dont l'objectif fondamental a été de mettre en commun les moyens industriels nécessaires à l'utilisation des avions, tout au moins ceux qui conduisent à des investissements très importants : chaines de grand entretien avion, révision des moteurs et bancs d'essais, révision des équipements nécessitant des bancs d'essais spécifiques, approvisionnement de pièces de rechange, engineering. C'est ainsi qu'au sein d'ATLAS (qui comprend actuellement Air France, Lufthansa, Alitalia, Sabena et Ibéria), le grand entretien avions est assuré sur deux chaines (1ère chaine : Boeing 747 : Air France - A 300 : Lufthansa - DC 10 : Alitalia - 2ème chaine : Boeing 747 : Iberia - A 300 : Air France) ; le grand entretien moteurs est assuré par Lufthansa : P.W. JT 9 - G.E. CF 6 50 E, par Air France : G.E. CF 6 50 C, par Ibéria : P.W. JT 8 - Olympus ; les autres équipements majeurs sont répartis essentiellement entre Sabena et Alitalia.

En ce qui concerne KSSU (qui comprend actuellement KLM, SAS, SWISSAIR et UTA) le grand entretien avion est assuré par K.L.M. : Boeing 747, par Swissair : DC 10, par SAS : A 300 B ; celui des moteurs, par SAS : P.W. JT 9, par KLM : G.E. CF 6 ; pour les équipements majeurs, UTA assure les trains, les inverseurs CF 6, les APV et l'hydraulique DC 10 et KLM l'hydraulique Boeing 747.

Dans l'un et l'autre groupe, frais d'entretien et répartition des charges de travail sont pris en compte, de façon à peu près similaire, dans un souci d'équilibre entre compagnies participantes.

Il est à noter que les résultats sont encore limités aux éléments les plus importants des flottes concernées et que les avantages tirés de ces groupes ne sont pas sans contraintes mais le bilan apparait positif.

Il convient, peut-être, d'ajouter une remarque touchant à certaines caractéristiques des réacteurs de la dernière génération, avions dits à grande capacité ou wide bodies. Les observations visent la flotte mondiale mais on a vu qu'ils constituaient un pourcentage important des appareils de transport aérien européen qui les utilise, d'ailleurs, largement en dehors du continent.

Parallèlement aux grandes qualités que chacun leur reconnait et aux avantages économiques qu'ils apportent, il reste que leur exploitation pose encore notamment divers problèmes de fiabilité de leurs groupes réacteurs, de tenues des pneumatiques, problèmes rendus plus aigus par une grande sensibilité à des incendies majeurs à développement très rapide. De plus, et c'est là que risque d'intervenir le facteur humain, les équipages techniques de tels avions, du fait de leur emplacement et des dimensions des appareils, se trouvent isolés dans une sorte de "tour d'ivoire". Ils peuvent ne plus avoir le contact direct avec les évènements à bord et n'ont pas non plus la communication facile avec le personnel navigant commercial. Le nombre de ces derniers s'est d'ailleurs accru, à bord d'un même avion, dans des proportions et dans des conditions telles qu'il est à peine exagéré de dire qu'il existe, dans certains cas, deux équipages dont la coordination est loin d'être évidente.

Les caractéristiques particulières du patchwork européen font ressortir un environnement, au sens le plus large du terme, assez unique et dont les incidences sur la sécurité aérienne sont parfois loin d'être négligeables.

Les disparités citées plus haut créent notamment des conditions ou entrainent des contraintes généralement peu propices au déroulement des activités aéronautiques :

- Le grand nombre de frontières et le survol de plusieurs territoires nationaux lors des trajets parfois très courts conduisent notamment à une charge de travail accrue pour les équipages et à la nécessité d'une coordination étroite entre centres de contrôle dépendants d'Etats différents.

- Corrélativement et en dépit de l'utilisation d'une langue aéronautique commune, des problèmes surgissent et sont dus :

  - soit au fait que les communications air/sol s'effectuent non seulement dans cette langue commune mais souvent aussi dans la langue du pays survolé, ce qui peut empêcher un équipage de saisir pleinement le déroulement du trafic dans lequel il est intégré,

  - soit, encore, lorsque surviennent des difficultés dont l'exposé et/ou la résolution exigent l'emploi de termes ne faisant pas habituellement partie de la phraséologie classique de la langue commune.

Il ne faut pas oublier, en outre, que deux ressortissants de pays différents utilisant une troisième langue théoriquement commune risquent fort d'aboutir, dans certains cas, à des incompréhensions d'autant plus dangereuses qu'elles ne sont pas toujours décelées comme telles.

Enfin, il est encore arrivé que devant une incompréhension manifeste, le pilote ou le contrôleur essaye de s'exprimer non plus dans la langue commune ou sa propre langue maternelle mais dans celle de son interlocuteur avec les risques supplémentaires que cela comporte : phraséologie absente ou inadaptée et faux sens voire contre sens parfois catastrophiques.

Pour les personnels au sol, spécialistes de l'entretien ou simple employé de piste, la confrontation avec des documents ou des indications présentés dans une langue étrangère est également une retombée défavorable de ces problèmes de langages et peut conduire à des risques non négligeables.

- Les divergences entre les législations nationales, qu'elles soient fondamentales dans leurs principes ou qu'elles ne portent que sur les différences d'application formelle de règles conçues dans le même esprit, soulèvent fatalement des difficultés qui ne sont pas sans répercussion sur le domaine technique ; par exemple, en entraînant des dérogations aux standards et pratiques recommandées mis au point par l'Organisation de l'Aviation Civile Internationale, dérogations qui en affaiblissent la portée. Sur le plan des enquêtes d'accidents d'aviation, en particulier, les exemples sont nombreux où le manque de flexibilité de certaines législations a joué dans un sens défavorable sur la bonne conduite des investigations techniques risquant ainsi de compromettre la sécurité aérienne. De même, les lois régissant la diffusion des rapports d'enquête entravent parfois la publication indispensable des données recueillies voire des enseignements formulées.

- La diversité des conditions climatiques régnant sur les aérodromes européens peut exiger, selon les cas, des équipements supplémentaires (généralement au sol), des procédures, une formation ou un entrainement assez différents. Si elles ne constituent, normalement, pour les navigants professionnels que des éléments peu favorables supplémentaires, parfois très délicats (aquaplanning par exemple), le déroulement des vols d'aviation générale peut en être plus fortement pénalisé : le grand tourisme aérien s'est fortement développé des dernières années et certaines conditions météorologiques rencontrées à l'étranger par des pilotes privés habitués à d'autres régions plus favorisées peuvent créer des difficultés génératrices d'accidents majeurs.

L'impact défavorable suscité par cet ensemble de caractéristiques particulières, plus ou moins disparates, est heureusement contrebalancé par les effets des convergences déjà citées :

- niveaux de base, de formation et de compétence technique des personnels adaptés aux activités aéronautiques de toutes natures,

- qualité, entretien, densité et assez bonne homogénéité des installations au sol habituées à traiter un trafic dense et dont une part non négligeable a été conçue et réalisée au sein de divers Etats européens,

- flotte aérienne dans l'ensemble moderne et bien équipée avec une homogénéité convenable, exploitée selon les règles de l'art et bénéficiant d'importantes usines de construction aéronautique et de sérieux moyens d'entretien répartis en de nombreux points de l'Europe, avec le concours supplémentaire de plusieurs centre d'essais au sol et en vol,

- Etats conscients de leurs responsabilités envers les activités aériennes et assurant un contrôle efficace des personnels et des matériels tant sur le plan de leur réglementation que sur celui de leur mise en oeuvre et sa surveillance,

- accords de coopération à tous les échelons, Etats, constructeurs, compagnies, visant à tirer le meilleur parti des moyens et compétences techniques et s'acheminant - à pas murement réfléchis - vers un niveau commun supérieur nécessaire à l'amélioration de la sécurité.

Dans ce contexte et, à ce stade, il est intéressant de tenter une approche statistique élémentaire des accidents survenus en Europe au cours des cinq ou six dernières années ; la présentation choisie, propre à chaque catégorie d'utilisation, résulte des éléments recueillis tant auprès de la banquecentrale, de données ADREP de l'OACI et de la C.E.A.C. que des renseignements fournis par divers Etats et d'autres sources fiables : séminaire de la Flight Safety Foundation, revues officielles ou presse aéronautique. Pour tenir compte du fait que certains rapports n'ont pas reçu de diffusion publique (précisément en raison de législations nationales strictes) ou que certaines enquêtes ne sont pas encore terminées, les indications ainsi fournies ne seront pas identifiées à une liste donnant le détail de chacun des accidents concernés.

L'objectif essentiel visé sera de faire ressortir l'importance du facteur humain par rapport à l'ensemble des facteurs causals retenus par les enquêteurs. Dans un second temps, on s'efforcera ensuite d'examiner dans quelle mesure des tendances principales pourraient être dégagées au sein même de cette rubrique.

Les accidents les plus spectaculaires ou, tout au moins, dont il est le plus parlé, sont, généralement, ceux concernant le Transport Public aérien. Avant de traiter les cas de cette catégorie en Europe, dont la flotte comporte 82 % de réacteurs, il est peut-être bon de présenter le tableau des taux de pertes totales de réacteur dans le monde, répartis par zone géographique (diapositive n°   ) ; depuis 1959 jusqu'en octobre 1981, près de 181 millions d'heures de vol ont été effectuées par ces appareils dont 371 ont été totalement perdus (toutes causes confondues). Il est facile de voir que, si l'on prend comme mesure de la sécurité le nombre d'heures de vol pour une perte totale, le progrès de la moyenne mondiale est assez spectaculaire ce chiffre, en effet, a plus que triplé de 1960 à 1981. Les taux différents toutefois très largement selon les régions considérés et,pour se borner à l'Europe, on peut noter qu'il est assez proche de la moyenne mondiale avec une amélioration plus lente,peut-être parce que mieux placé au départ, mais aussi qu'il est nettement meilleur que la moyenne mondiale si l'on exclut les chiffres concernant les Etats-Unis.

Les données suivantes, concernant les années 1976 à 1981 inclus, ont été établis exclusivement pour le transport public européen (avion au-dessus de 9 000 kg) et ne visent donc que les accidents (au sens de l'Annexe 13 de l'OACI) survenus sur les territoires des 22 Etats de la CEAC à des appareils immatriculés dans l'un quelconque des ces Etats. Il n'a pas été tenu compte des accidents survenus en Europe à des appareils étrangers, non plus que de ceux des appareils européens hors du continent. De plus, ne figurent pas dans ces chiffres ceux où des occupants ou des tiers ont été tués ou blessés sans qu'il y en soit résulté un dommage pour le matériel.

Il est possible que ces données ne soient pas totalement exhaustives, mais les quelques manquants sont pratiquement sans incidence sur la signification des résultats

Compte tenu des critères ainsi déterminés, 63 accidents ont été recensés : 34 accidents de réacteurs, 24 accidents de turbopropulseurs et seulement 5 accidents d'avions à pistons (l'exclusion de la statistique des accidents survenus hors d'Europe donne aux turbopropulseurs une importance plus grande que leur pourcentage réel dans la flotte considérée). Ces accidents ont entrainé la destruction totale de 11 appareils, 52 ayant été endommagés. A noter que 24 % se sont produit au décollage, 13,2 % en route et 48 % à l'approche et l'atterrissage. Pour l'analyse des causes, rappelons qu'elles ont été traitées par facteurs causals, c'est-à-dire que pour un même accident ont été notés, sans ordre préférentiel, chacun des facteurs susceptibles d'avoir joué un rôle ; de plus, afin de tenter de mieux cerner le facteur concerné, il a pu lui-même faire l'objet de plusieurs rubriques : par exemple un manque de coordination entre équipage et contrôleur a pu être indiqué sous deux intitulés :personnel en vol - commandant de bord - manque de coordination avec le sol et personnel au sol - contrôleur - manque de coordination avec l'équipage.

Un premier tri de ces facteurs donne la répartition suivante :

| Personnel | Matériel | Conditions météorologiques | Infrastructure terrain | Divers indéterminés |
|---|---|---|---|---|
| 63 % | 13 % | 9 % | 7 % | 8 % |

Si l'on se limite aux facteurs imputables au personnel, premiers facteurs humains en évidence, la présentation ci-après, encore très résumée, est un peu plus instructive.

Transports Aérien
Européen

Aéronefs de plus de
9 000 kg (20 000 lbs)

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Accidents survenus au cours
des années 1976 à 1981

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Facteurs imputables au personnel: 63 %

Personnel en vol : 73,4 %    Personnel au sol : 26,6 %

**Commandent de bord : 66 %**

- inattention, manque de surveillance : 22,6%
- utilisation machine incorrecte : 13 %
- non respect des procédures :13%
- technique insuffisante :9,7 %
- réaction trop tardive : 9,7 %
- mauvaise coordination avec le sol : 6,4 %
- check list déficiente : 6,4 %
- mauvaise décision : 6,4 %
- décision tardive : 6,4 %
- non respect des limitations : 6,4 %

**Autre membre d'équipage : 34%**

- technique insuffisante :43,75 %
- réaction trop tardive : 18,75%
- utilisation machine incorrecte : 12,5 %
- mauvaise coordination avec le sol : 12,5 %
- assistance insuffisante au commandant de bord : 6,25 %
- performance diminuées par médicaments : 6,25%

**Contrôle du trafic en vol : 47,1%**

- inattention, manque de surveillance : 50 %
- insuffisant : 25%
- manque de coordination avec l'équipage : 25 %

**Entretien avion : 23,5%**

- mauvaise exécution du travail : 100 %

**Autre personnel : 29,4%**

- mesures incorrectes : 40 %
- mauvais guidage : 20 %
- informations erronées : 20 %

(*VOIR AUSSI PAGE 2–15*)

Le détail ainsi donné, déjà légèrement regroupé, provient directement des indications figurant dans les résultats des enquêtes ; il a cependant été peu facile de standardiser les postes de chacune des sous-rubriques ; en effet, en dépit d'une certaine codification des facteurs causals (en principe, inspirée du système ADREP de l'OACI), il est rare que, dans un rapport narratif, ressorte de façon evidente un tel découpage et, par contre, le découpage figurant dans un formulaire déjà codé ne représente pas toujours les conclusions nuancées d'une enquête.

Il n'est malheureusement pas possible de détailler de façon identique les indications concernant les activités du travail aérien pour les 22 Etats déjà cités, les données n'ayant, semble-t-il, pas encore fait l'objet de collectes réellement ordonnées, les approches de divers Etats étant assez différentes, et certains chiffres paraissant peu homogènes ; on peut simplement avancer que la part du facteur humain tend à dé[illegible]ser 75 % ce qui n'est pas étonnant, les conditions particulières de telles activités faisant le plus souvent du pilote un homme orchestre sur lequel repose la majorité des responsabilités.

L'aviation générale européenne est, par contre, plus facile à cerner : en effet, dans le cadre de la Commission Européenne de l'Aviation Civile, les accidents dans l'"aviation privée" font depuis juin 1964 l'objet d'un recueil annuel des renseignements concernant les résultats essentiels des enquêtes tant pour les avions que pour les planeurs.

Les grandes lignes de ces données montrent que pour une flotte qui est passée d'environ 10.000 avions en 1964 à près de 26.000 début 1981 et de 5.000 planeurs à 12.000 pendant la même période, les accidents ont évolué :-pour les avions de 800 à 1.000 accidents ayant entrainé de 340 à 500 tués et blessés et la destruction totale ou partielle de 380 à 700 appareils.

- pour les planeurs, de 300 à 550 accidents ayant entrainé 300 à 160 tués et blessés et la destruction totale ou partielle de 240 à 460 appareils.

Les dis
Les diapositives suivantes permettent de préciser cette évolution :

- diapositive n° 15 : nombre d'avions, de planeurs, mouvements et heures de vol (64 - 80)
- diapositive n° 16 : nombre total d'accidents, nombre d'accidents avec dommages corporels - avions et planeurs (64 - 80)
- diapositive n° 17

A l'occasion de ce tableau, il est à noter que le nombre total d'accidents par milliers d'heures de vol dans l'Aviation Générale aux Etats-Unis est deux fois moindre qu'en Europe mais le pourcentage des facteurs humains est pratiquement de même ordre.

- diapositive n° 18 : taux d'accidents et taux d'accidents avec dommages corporels par mille heures de vol - avions - planeurs (64 - 80)
- diapositive n° 19 : nombre de tués et blessés par 100.000 heures de vol - avions planeurs (64 - 81)

En ce qui concerne la répartition des facteurs causals, elle montre sur les dix sept années étudiées une constance très remarquable pour une aussi longue période. Les chiffres suivants permettent de schématiser les importances respectives des principales rubriques :

- facteurs imputables au personnel : moyenne de 62 % dont 95 % pour les pilotes
  1,5 % pour les autres personnels à bord
  3,5 % pour les personnels au sol
- facteurs imputables au matériel : moyenne de 14 %
- facteurs imputables aux conditions météorologiques : moyenne de 11, 5 %
- facteurs imputables à l'infrastructure : moyenne de 5 %
- facteurs imputables à des causes diverses ou indéterminées : moyenne de 7,5 %

Depuis 1972, faute d'une décision favorable de la part des Etats membres, la Commission Européenne de l'Aviation Civile n'a pas cru devoir continuer le recueil de données permettant d'étudier le détail de chacun des sous-facteurs concernant le personnel : technique insuffisante, inobservation des règles, mauvaise décision ..., et il serait hasardeux d'avancer des chiffres plus ou moins précis à cet égard encore que les éléments connus incitent à penser que le non respect des règles et procédures représente un pourcentage particulièrement important ainsi que la rubrique technique insuffisante due à une formation ou un entrainement défectueux.

Sur le plan des accidents d'appareils militaires, qui sort quelque peu de ma spécialité, les renseignements disponibles dans la presse aéronautique spécialisée tendent à indiquer, pour les année 1975 à 1980 inclus, que l'ordre de grandeur des facteurs causals concernant le personnel, pour les appareils européens, est apparemment légèrement supérieur à 55 %, ce qui est tout à fait comparable aux chiffres mis en évidence pour les appareils civils, en particulier dans le transport aérien.

Ces diverses présentations statistiques, pour incomplètes qu'elles soient, ont déjà le mérite de confirmer les données de l'intuition sur l'importance des facteurs causals imputables au personnel et, dans ces facteurs, la prépondérance de ceux concernant l'équipage. Toutefois, les appréciations émises par les enquêteurs ou les statisticiens qui ont traité les rapports d'enquête ne paraissent pas permettre des constatations sans équivoque, ni une utilisation directe pour l'étude du facteur humain.

Il est évident, et la consultation du détail des facteurs causals imputables au personnel dans le transport aérien le montre bien, que les rubriques choisies sont souvent très voisines les unes des autres : quelle est la différence entre "mesures (destinées à fournir des données) incorrectes" et "informations erronées" ou encore entre "décision tardive" et "mauvaise décision" ? Les mesures incorrectes fourniront, normalement, des informations erronées et une décision tardive sera, finalement, équivalente à une mauvaise décision.

Par ailleurs, de telles appréciations ne peuvent être étudiées de façon isolée de leur contexte : la décision tardive du Commandant de bord provoquée par un évènement imprévisible et urgent ne peut entrer dans l'analyse de façon identique à la décision tardive prise dans des conditions ne présentant pas ce caractère supplémentaire.

La définition même du facteur humain est encore très flous et donc sujette à une assez grande variété d'interprétation. Il parait probable qu'un autre enquêteur disposant des mêmes éléments de base que ceux utilisés dans ce document aurait de bonnes chances et de bonnes raisons de faire des choix quelque peu différents de ceux dont les résultats viennent de vous être présentés. On peut d'ailleurs légitimement penser que l'assimilation facteurs causals imputables en personnel et facteurs humains n'est pas entièrement correcte. Il parait probable effectivement que les facteurs "personnel" mis en évidence dans la statistique ne tiennent pas compte de l'ensemble des facteurs humains plus ou moins dissimulés dans les autres facteurs causals.

Il semble étonnant que, depuis les débuts de l'histoire de l'aviation, les rapports d'enquête sur les accidents aient aussi souvent mis en cause le facteur humain sans que, contrairement aux autres facteurs dont l'apparition est pourtant bien moins fréquente, il ait été encore possible de définir des méthodes d'études suffisamment rigoureuses ou tout au moins, de faire en sorte que le travail considérable que représente une enquête d'accident puisse être mieux utilisé à cet effet.

De nombreuses approches ont cependant été tentées et de multiples moyens ont été suggérés. Parmi tous les critères proposés un nombre croissant d'enquêteurs a généralement tendance à étudier le facteur humain sous le triple aspect de l'aptitude physique, de la capacité intellectuelle et de l'équilibre psychique ainsi que de leurs interactions éventuelles. Bien entendu, une telle forme d'analyse doit s'appliquer à chacun des individus directement ou indirectement concernés dans la genèse d'un accident d'aviation, qu'il s'agisse de personnels navigants ou non, au sol comme en vol.

Le plus souvent, c'est la somme de facteurs dont chacun, pris isolément se situe en-dessous du seuil du risque, qui créera la surcharge propice à l'accident ou aggravera une situation au préalable peu ou pas dangereuse. Cette addition d'éléments simples résultera d'ailleurs aussi bien de la combinaison des facteurs techniques et humains que des seuls facteurs humains.

Au fur et à mesure du déroulement de l'enquête, les facteurs humains mis en évidence par les investigations techniques doivent, alors, non seulement être caractérisés par leurs incidences propres mais aussi par leurs résultantes, en les examinant par rapport au contexte situationnel et l'enquêteur doit s'attacher à en préciser le rôle déclenchant ou aggravant.

Dans le cadre des activités aéronautiques, deux volets distincts peuvent être choisis pour tenter une classification, peut être arbitraire, des principaux facteurs humains : un premier ensemble sera constitué de facteurs intrinsèques, définis comme étant pratiquement étrangere au personnel de conduite de l'aéronef et s'appliquant donc au personnel non navigant et à ses différents services ainsi qu'aux supports du matériel aéronautique et à son environnement - un deuxième ensemble sera réservé aux facteurs intrinsèques définis comme directement liés au personnel navigant

Une telle division présente un caractère quelque peu artificiel, ne serait-ce qu'en raison des inévitables points communs, mais elle semble assez commode parce que facilement utilisable pour l'enquêteur qui, généralement, n'a ni la formation, ni la compétence du physiologue, du psychiatre ou du psychologue. Il n'est cependant pas exclu que ces derniers puissent aussi trouver quelque avantage.

En fonction de cette classification, il peut paraitre intéressant de citer quelques uns des points sur lesquels l'enquêteur aura notamment à faire porter ses recherches.

Pour les personnels non navigants, qu'on ne peut espérer tous citer ici, on se bornera aux catégories suivantes les plus importantes ou les plus fréquemment en cause.

<u>Personnel de conception et fabrication des matériels</u>

Recherche de l'erreur humaine :

- dans l'application des règles de l'art
- dans une conception faisant trop appel à la performance de l'équipage ou n'ayant pas prévu une marge suffisante pour l'erreur possible
- dans une conception facilitant l'erreur de montage ou d'utilisation
- dans le manque de redondances souhaitables ou dans leur réalisation imparfaite
- dans la prise en compte de l'éventualité d'un accident pour en minimiser les conséquences
- dans les choix des matériaux ou des aménagements en fonction des critères de survie des occupants
- dans le contrôle de la conception et de la fabrication
- dans la conception et la réalisation des modifications impératives ou non
- dans l'établissement et la diffusion de la documentation
- dans l'assistance fournie par le service après-vente
- dans la formation des personnels du constructeur et des utilisateurs

Personnel d'entretien

Recherche de l'erreur humaine ayant entraîné une défaillance technique à partir de l'examen :

- du nombre et de la qualification des personnels en cause, de leurs équipements, de leurs horaires et charges de travail,
- de la qualité et de la circulation de l'information qui leur est destinée,
- des relations établies avec le personnel navigant,
- de la sensibilisation aux problèmes de sécurité,
- des méthodes d'entretien et du contrôle,
- de la nature de l'environnement.

Personnel de contrôle du trafic (en route - approche - aérodrome)

Recherche d'une erreur humaine ayant entrainé une eituation de vol difficile ou dangereuse : à partir de l'examen

- du nombre et de la qualification des personnels en cause, de leurs équipements, horaires, tableaux de service et charges de travail,
- des méthodea de contrôle,
- de la validité des informations reçues ou données,
- de la qualité des transmissions téléphoniques ou radio, de la valeur et de la justification des indications ou consignes formulées,
- dee conséquences éventuelles des tranemiesions susceptibles de créer ou aggraver une situation de danger,
- de la qualité dos rapports avec le personnel navigant
- des contraintes psycho-physiologiques propres à l'environnement des différents postes de contrôle du trafic

Personnel de l'information météorologique

Recherche d'une erreur humaine ayant entrainé une situation de vol difficile ou dangereuse : à partir de l'examen

- du nombre et de la qualification du personnel en cause, de leurs moyens, horaires, tableaux de service et charges de travail,
- de la qualité des observations et des prévisions,
- de la nature et la qualité de la transmission des informations,
- de la nature et la qualité des rapports avec les personnels navigants concernés

Personnel médical

Recherche de l'erreur humaine ayant contribué à des situations de rieque : à partir de l'examen

- des conditions de délivrance de certains certificats d'aptitude, de maintien d'aptitude ou de dérogations potentiellement dangereuses ou incompatibles avec toutes lee conditions du vol,
- des traitements en cours et de la nature des médicaments prescrits ou utilisés, peu ou pas compatibles avec les diverses formes de l'activité aéronautique,
- de l'approbation de certaines conditione de travail au sol ou en vol,
- de la circulation et de l'utilisation de l'information disponible ou recueillie,
- les rapports avec le personnel navigant
- de la sensibilisation aux problèmes de eécurité aérienne

Personnel de formation

Recherche de l'erreur humaine ayant contribué à une défaillance technique ou à une situation de vol difficile ou dangereuse : à partir de l'examen

- de l'adéquation de la formation et de la nature du travail visé, qu'il s'agisse de personnels navigante ou non,
- du contrôle effectif de la qualité de la formation donnée et reçue
- de la valeur d'exemple que revêt la conduite d'un formateur pendant et au dehors de l'instruction,
- de la prise de risques inutiles ou inappropriés
- de la complaisance éventuelle dans la délivrance des titres ou qualifications attestant un niveau satisfaisant,
- de l'environnement au cours de la formation.

### Personnel de direction

Recherche de l'erreur humaine ayant contribué à une défaillance technique ou à une situation de vol difficile :
à partir de l'examen :

- des relations entre l'autorité et les personnels navigants ou non, des pressions qui peuvent en découler, de part et d'autre,
- de l'influence des choix et décisions de politique générale et des conséquences qu'elles ont pu entrainer dans chacune des activités citées dans les rubriques précédentes.

### Personnel impliqué dans d'autres contextes situationnels

La recherche de l'erreur humaine s'effectuera de façon identique mais en fonction de chaque cas d'espèce :
par exemple, en examinant les dépositions des témoins d'un accident à la lumière de leurs motivations conscientes ou inconscientes ou des diverses pressions dont ils peuvent être l'objet.

En ce qui concerne le personnel navigant, la liste est longue des facteurs intrinsèques qui lui sont directement liés et leur nature exigera souvent, pour l'enquêteur, le recours au praticien spécialiste ; nous nous limiterons aux plus évidents et à quelques unes de leurs caractéristiques :

### Défaillance humaine professionnelle

Toutes fautes professionnelles à caractère directement technique : maladresse, faute de pilotage, mauvaise utilisation de la machine ou de diverses commandes, actions inadéquates manifestement inappropriées à la situation et cela sans qu'aucune autre explication puisse être donnée (la faute ne peut être rattachée à une défaillance mécanique de l'avion, ni à une défaillance médicale de l'aptitude générale et psychologique du pilote, ni à une situation réellement difficile).

### Défaillance propre à l'excès de confiance, à l'indiscipline

Souvent citée mais rarement explicable, elle peut résulter de l'inexpérience comme d'une trop grande habitude. Fréquemment constatée chez de jeunes pilotes, on la retrouve cependant, plus ou moins, à tous les niveaux de qualification. Peut être facilitée par une formation inadaptée et un encadrement insuffisamment rigoureux, elle ressort probablement de facteurs essentiellement psychologiques.

### Défaillance physique individuelle plus ou moins préexistante (incapacité soudaine ou non en vol)

La plus dangereuse (en particulier dans les phases décollage et atterrissage) est l'incapacité soudaine. Elle peut être mortelle - dans ce cas, généralement cardiaque - ou se traduire par des troubles psychiques - d'un développement brutal et incontrôlable (comme cela a été récemment le cas). Le niveau médical actuel ne permet pas, semble-t-il, d'assurer un dépistage systématiquement complet de la préexistence de tels risques ou de leur développement.

D'autres formes d'incapacitation, les calculs rénaux par exemple, peuvent créer des situations de vol extrêmement difficiles.

A noter encore que les personnels navigants sont fréquemment soumis à des régimes d'alimentation parfois étranges et qu'il peut en résulter diverses formes d'intoxications alimentaires susceptibles de se manifester à tout moment de leurs activités, donc conduire à une incapacité plus ou moins soudaine en vol.

### Défaillances physiques accidentelles

Hors les défaillances physiques classiques auxquelles les navigants sont soumis comme les autres hommes, il reste que les effets des médicaments, prescrits par un médecin non averti du fait que son patient pratique l'aviation ou de médicaments pris de la propre initiative du pilote sans surveillance, ni ordonnance médicale, peuvent se révéler tout à fait néfastes. Les diverses drogues, supposées anodines, destinées à combattre le décalage horaire, un surmenage momentané ou une légère fatigue apparente sont des exemples classiques.

## Défaillances physiques dues à l'environnement du vol

Altitude, température, hygrométrie, accélération, ... constituent autant de paramètres susceptibles d'avoir des effets défavorables sur le niveau de performances. A ces facteurs peuvent venir s'ajouter des stress supplémentaires dus éventuellement aux conditions météorologiques, à une phase de vol délicate, à des aides à la navigation à l'approche et l'atterrissage, ou des installations aéroportuaires défectueuses ou non conformes. Cet ensemble de facteurs de situation pourra jouer directement sur le comportement psycholcgique et l'état physique du personnel navigant.

## Illusions sensorielles

Les illusions visuelles, les phénomènes de désorientation sont de tous ordres : décollage d'unc zone éclairée vers une zone obscure, relief de pente insensiblement croissant "white out", erreur de lecture, particularités de la vision nocture, passage de la vision des instruments à la vue extérieure... Leur existence est bien connue, mais leur rôle dans le déroulement d'un accident est rarement facile à démontrer.

## Toxicologie "normale" ou accidentelle

L'usage du tabac altère l'état d'éveil, l'exprit critique et la vision nocturne, quelques cigarettes accroissent l'altitude réelle.

Les effets de l'alcool sont également connus et, bien avant d'atteindre le minimum légalement admis, les performances du sujet se dégradent.

A ces intoxications "normales" peuvent s'ajouter diverses intoxications accidentelles plus ou moins insidieuses : la présence de fissures dans un brûleur de chauffage cockpit peut entrainer un dégagement d'oxyde de carbone, la combustion de divers matériaux d'aménagements intérieurs provoque une grande variété de gaz toxiques ou de fumées susceptibles, au minimum, d'altérer les facultés psychomotrices ou la simple vision.

## Défaillances psychologiques :

L'enquêteur, non médecin, pourra s'attacher :

- aux manifestations émotionnelles : peur, panique
- aux perturbations d'humeur
- aux aspects extérieurs des troubles de la personnalité : confiance excessive, rigorisme,
- aux déficiences intellectuelles : attention, mémoire, jugement, communication
- à certaines prises de décisions inadéquates : fautes de procédures, erreurs de calcul.

Ces éléments devront être, si possible, examinés dans un contexte tenant compte des antécédents, de la personnalité et de l'environnement familial et social.

## Défaillances morales

Certains cas de transgression consciente et inutile des règles de sécurité, le non respect de consignes de vol, d'utilisation de la machine, peuvent constituer, de la part de personnel navigant normalement compétent et averti, des négligences d'ordre moral. Une telle conduite délibérée, contrevenant aux règles communes, tend à s'assimiler aux phénomènes associaux.

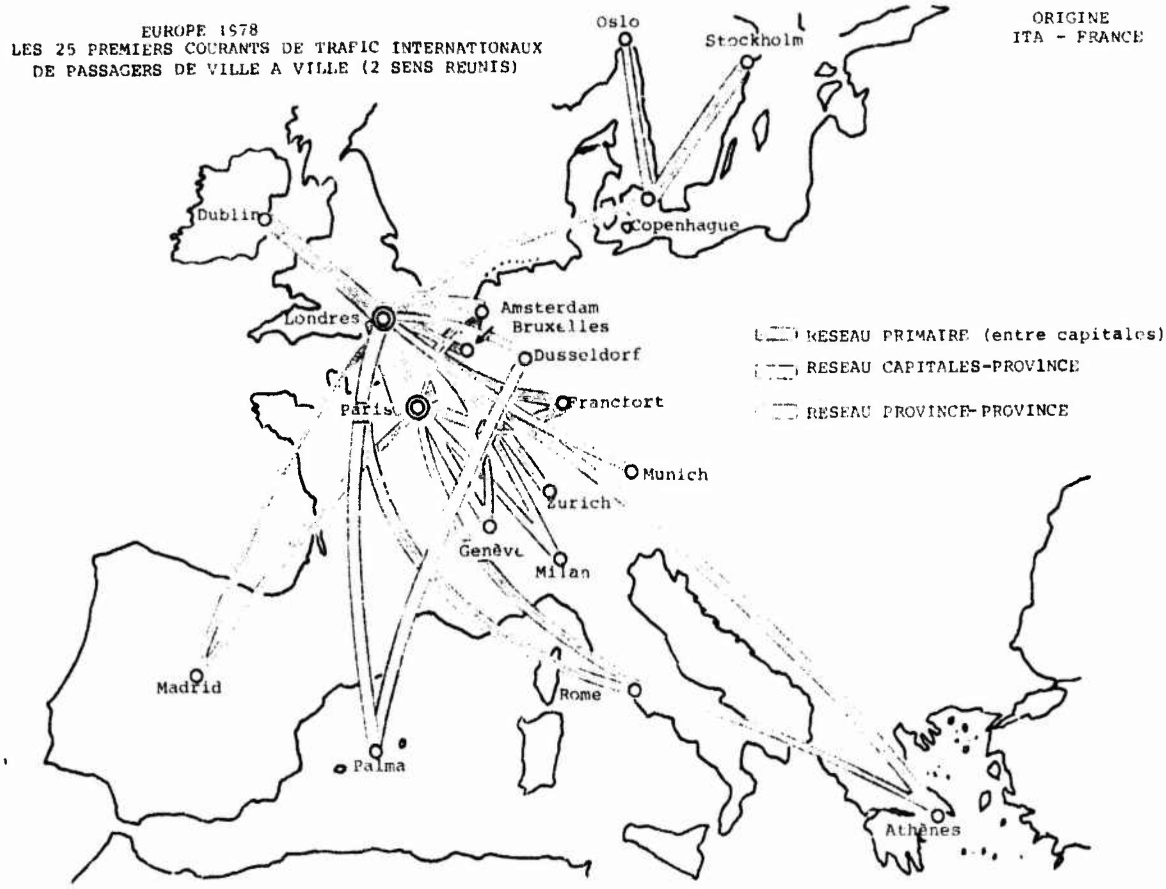
Il reste enfin que tout enquêteur doit être conscient qu'un facteur apparent peut en cacher d'autres, l'erreur attribuée au seul pilote n'a peut-être pu survenir que dans la mesure où il s'est trouvé en condition pour la commettre : l'exemple est classique d'une mauvaise conception d'une présentation instrumentale autorisant la confusion de deux paramètres ou encore de commandes identiques placées côte à côte et permettant le mauvais choix voire la manoeuvre simultanée involontaire.

La part des facteurs humains dans les accidents d'aviation mondiaux et, plus particulièrement européen, montre qu'il existe un vaste champ d'action où des mesures peuvent être prises pour améliorer la sécurité.

Il ne peut être question de supprimer radicalement ces facteurs ce qui serait un objectif parfaitement irréaliste, il est plus que probable, en effet, qu'il existe un minimum incompressible tenant à la nature même de l'homme. Par contre, tenter de réduire le nombre des accidents ou d'en minimiser les conséquences en agissant sur le facteur humain devrait être un but à la portée du monde aéronautique.

Ces constatations ne sont pas nouvelles, mais il ne semble pas, en dépit des nombreux travaux entrepris, que des tentatives très fructueuses et, surtout, des méthodes appropriées se soient faites jour.

Du seul point de vue de l'enquêteur, s'il estime être généralement à même de déterminer les grandes lignes des facteurs humains ayant contribué à un accident d'aviation, il lui parait manquer trop souvent de moyens pour aller vraiment au fond des choses et formuler ensuite des recommandations appropriées. C'est dans ce sens que l'on pourrait utilement comprendre cette paraphrase d'une citation connue "lorsque les investigations techniques ont conclu à l'erreur humaine c'est alors que l'enquête doit commencer".




THE 25 FIRST INTERNATIONAL PASSENGER TRAFFIC FLOWS
FROM TOWN TO TOWN
(both ways added) 1974 to 1978

(thousands of pax.)

| Courants de trafic | 1974 | 1978 | Average annual growth |
|---|---|---|---|
| Paris - Londres | 1.814,4 | 2.010,9 | + 2,6 |
| Amsterdam - Londres | 1.[illegible]7,9 | 1.171,5 | + 3,3 |
| Dublin - Londres | 807,4 | 953,0 | + 4,2 |
| Copenhague - Stockholm | 630,9 | 737,5 | + 4,0 |
| Francfort - Londres | 506,2 | 672,0 | + 7,3 |
| Athènes - Londres | 324,6 | 648,7 | + 18,9 |
| Dusseldorf - Palma | 441,6 | 633,8 | + 9,5 |
| Londres - Zurich | 457,2 | 625,5 | + 8,2 |
| Londres - Palma | 632,8 | 618,8 | - 0,6 |
| Bruxelles - Londres | 560,1 | 604,5 | + 1,9 |
| Genève - Paris | 554,5 | 591,2 | + 1,6 |
| Copenhague - Oslo | 423,9 | 566,6 | + 7,5 |
| Genève - Londres | 385,0 | 512,6 | + 7,4 |
| Londres - Milan | 420,9 | 512,3 | + 5,0 |
| Francfort - Paris | 387,6 | 504,2 | + 6,8 |
| Londres - Rome | 424,4 | 476,0 | + 2,9 |
| Milan - Paris | 406,3 | 463,3 | + 3,3 |
| Copenhague - Londres | 383,3 | 430,2 | + 2,9 |
| Londres - Madrid | 345,1 | 429,2 | + 5,6 |
| Paris - Rome | 344,1 | 420,4 | + 5,1 |
| Madrid - Paris | 324,2 | 410,3 | + 6,1 |
| Athènes - Rome | 255,4 | 405,6 | + 12,3 |
| Dusseldorf - Londres | 292,2 | 392,9 | + 7,7 |
| Amsterdam - Paris | 381,2 | 390,7 | + 0,6 |
| Londres - Munich | 329,8 | 362,9 | + 2,4 |
| Total for 25 legs | 12.861,0 | 15.494,7 | + 4,8 |

Diapositive 13

La part dee facteurs humains dans lee accidents d'aviation mondiaux et, plus particulièrement européen, montre qu'il existe un vaste champ d'action où des mesures peuvent être prises pour améliorer la sécurité.

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Transports Aérien Européen
European Air Transport

Aéronefs de plus de 9 000 kg (20 000 lbs)
Aircraft above 9 000 kg (20 000 lbs)

Accidents survenus au cours des années 1976 à 1981
Accidents in the years 1976 - 1981

-----------

Facteurs imputables au personnel
Personnel causal factors : 63 %

Personnel en vol
Personnel in the aircraft : 73,4 %

Personnel au sol
Personnel on the ground : 26,6 %

**Commandant de bord / Captain : 66%**

- inattention, manque de surveillance : 22,6%
- inattention, lack of supervision : 22,6 %

- utilisation machine incorrecte : 13 %
- aircraft incorrect utilisation : 13 %

- non respect des procédures : 13 %
- procedures disrespect : 13 %

- technique insuffisante : 9,7 %
- insufficient technique : 9,7 %

- réaction trop tardive : 9,7 %
- slow reaction : 9,7%

- mauvaise coordination avec le sol : 6,4 %
- poor coordination with the ground : 6,4%

- check list déficiente : 6,4 %
- deficient check list : 6, 4 %

- mauvaise décision :6,4%
-wrong decision : 6,4%

- décision tardive: 6,4%
- slow decision : 6,4 %

- non respect des limitations : 6,4%
- limitations disrespect : 6, 4%

**Autre membre d'équipage / Other crew member : 34 %**

- technique insuffisante : 43,75 %
- insufficient technique : 43,75 %

- réaction trop tardive : 18,75 %
- slow reaction:18,75%

- utilisation machine incorrecte : 12,5 %
- aircraft incorrect utilisation : 12,5 %

- mauvaise coordination avec le sol :12,5%
- poor coordination with the ground : 12,5%

- assistance insuffisante au commandant de bord : 6,25 %
- insufficient assistance to the captain : 6,25 %

- performance diminuée par médicaments :6,25%
- performance degraded by drugs : 6,25 %

**Contrôle du trafic en vol / Air Traffic control : 47,1%**

- inattention manque de surveillance :50%
- inattention, lack of supervision : 50 %

- insuffisant : 25 %
- insufficiency : 25%

- manque de coordination avec l'équipage : 25 %
- lack of coordination with the crew : 25 %

**Entretien avion / Aircraft maintenance : 23,5%**

- mauvaise exécution du travail : 100 %
- poor work : 100 %

**Autre personnel / Other personnel : 29,4%**

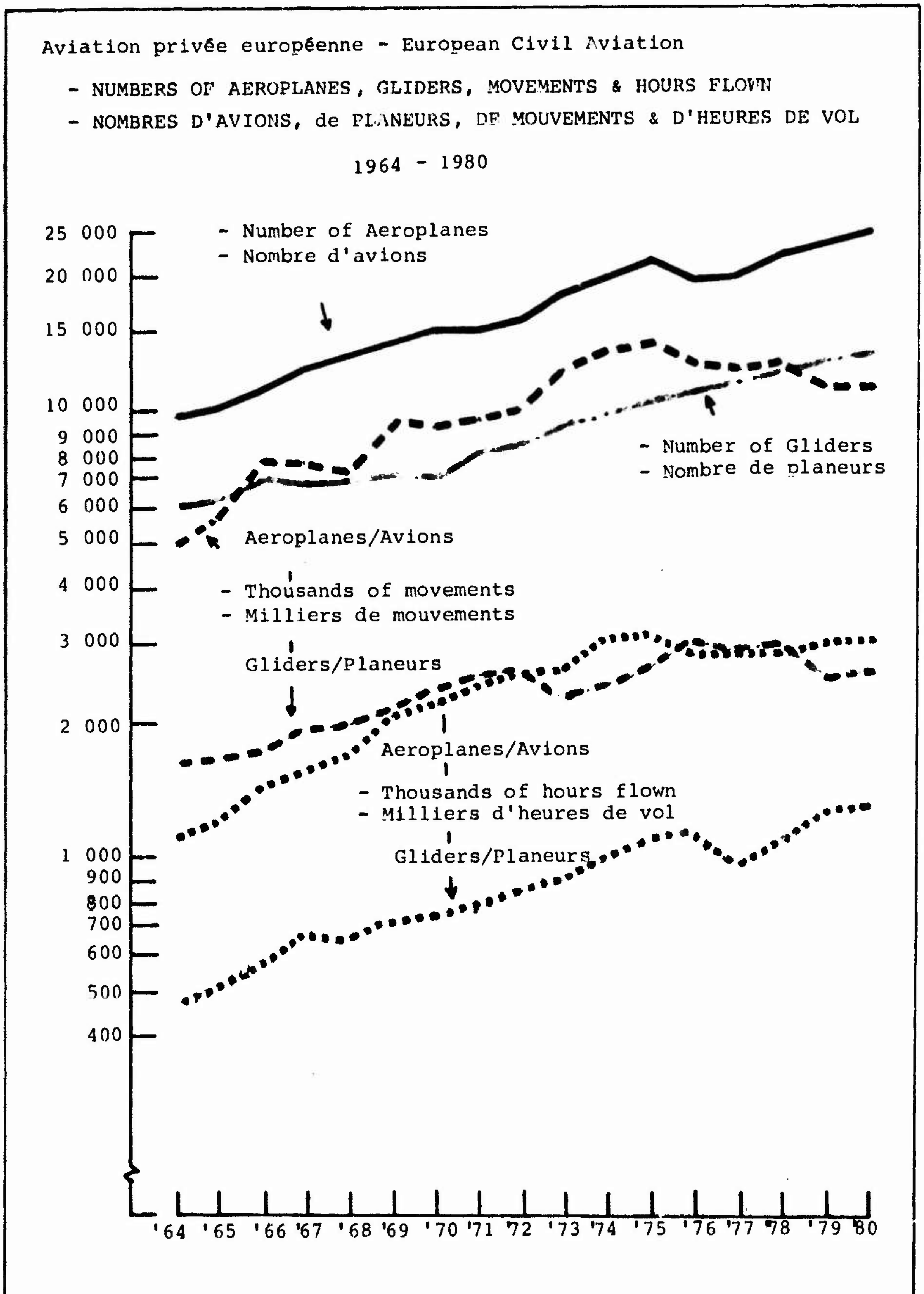
- mesures incorrectes : 40 %
- incorrect measurements:40%

- mauvais guidage : 20 %
- poor guidance : 20 %

- informations erronées: 20%
- wrong informations : 20 %

(VOIR AUSSI PAGE 2–7)

Diapositive 14

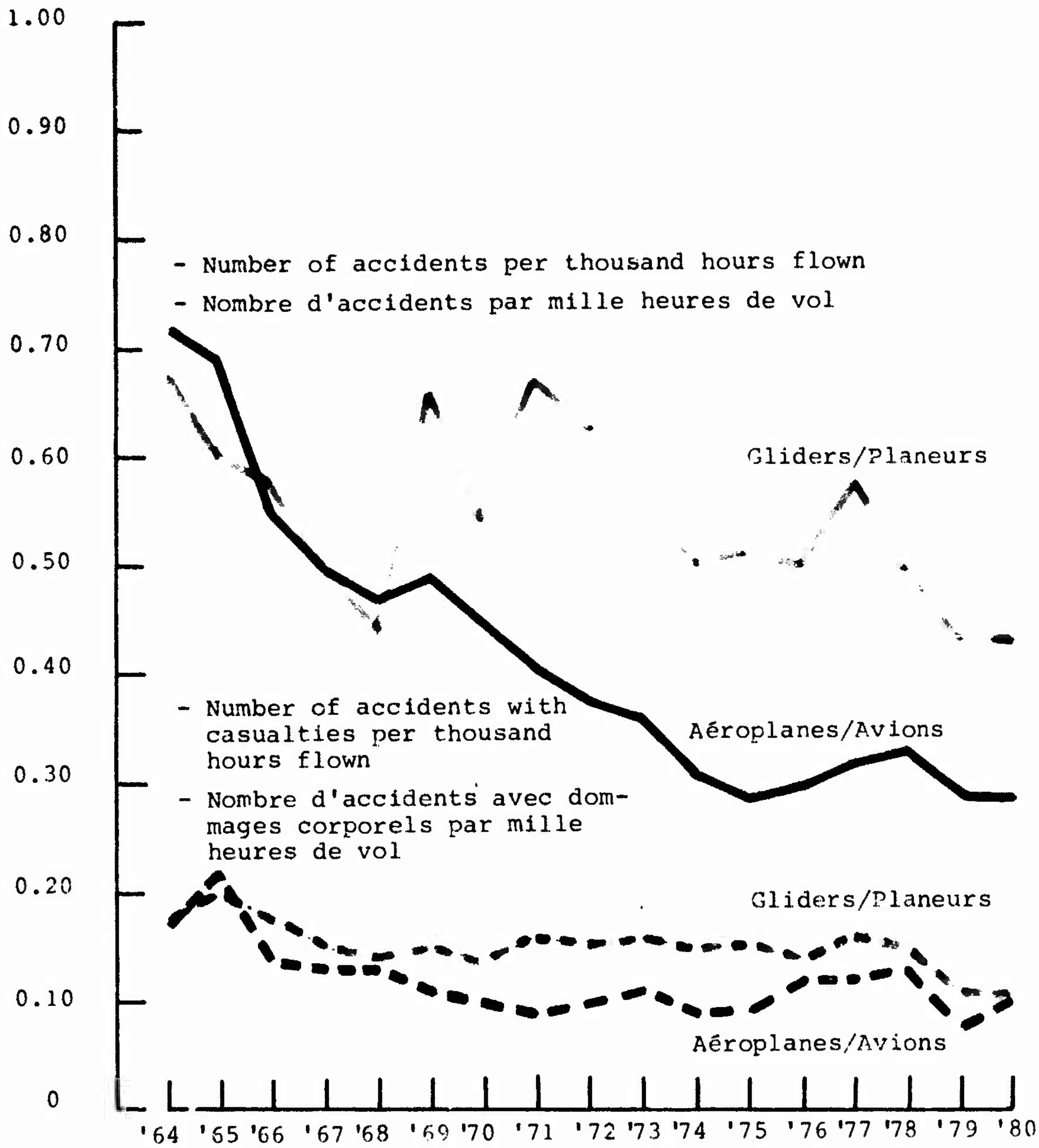



Diapositive 15

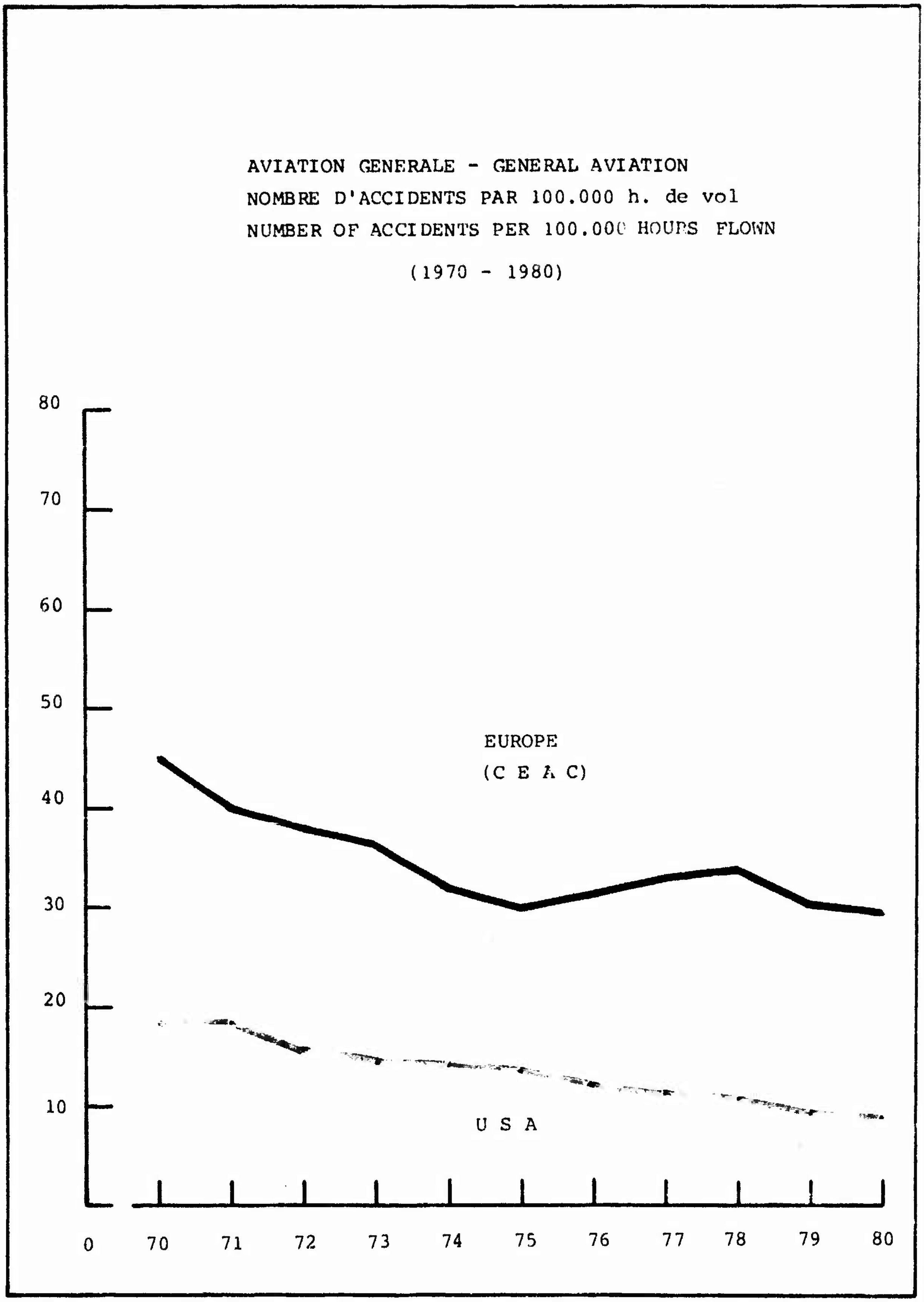
Aviation Privée Européenne - European Civil Aviation

- NUMBER OF ACCIDENTS , ACCIDENTS WITH CASUALTIES PER THOUSAND HOURS FLOWN
- NOMBRE D'ACCIDENTS, D'ACCIDENTS AVEC DOMMAGES CORPORELS PAR MILLE HEURES DE VOL

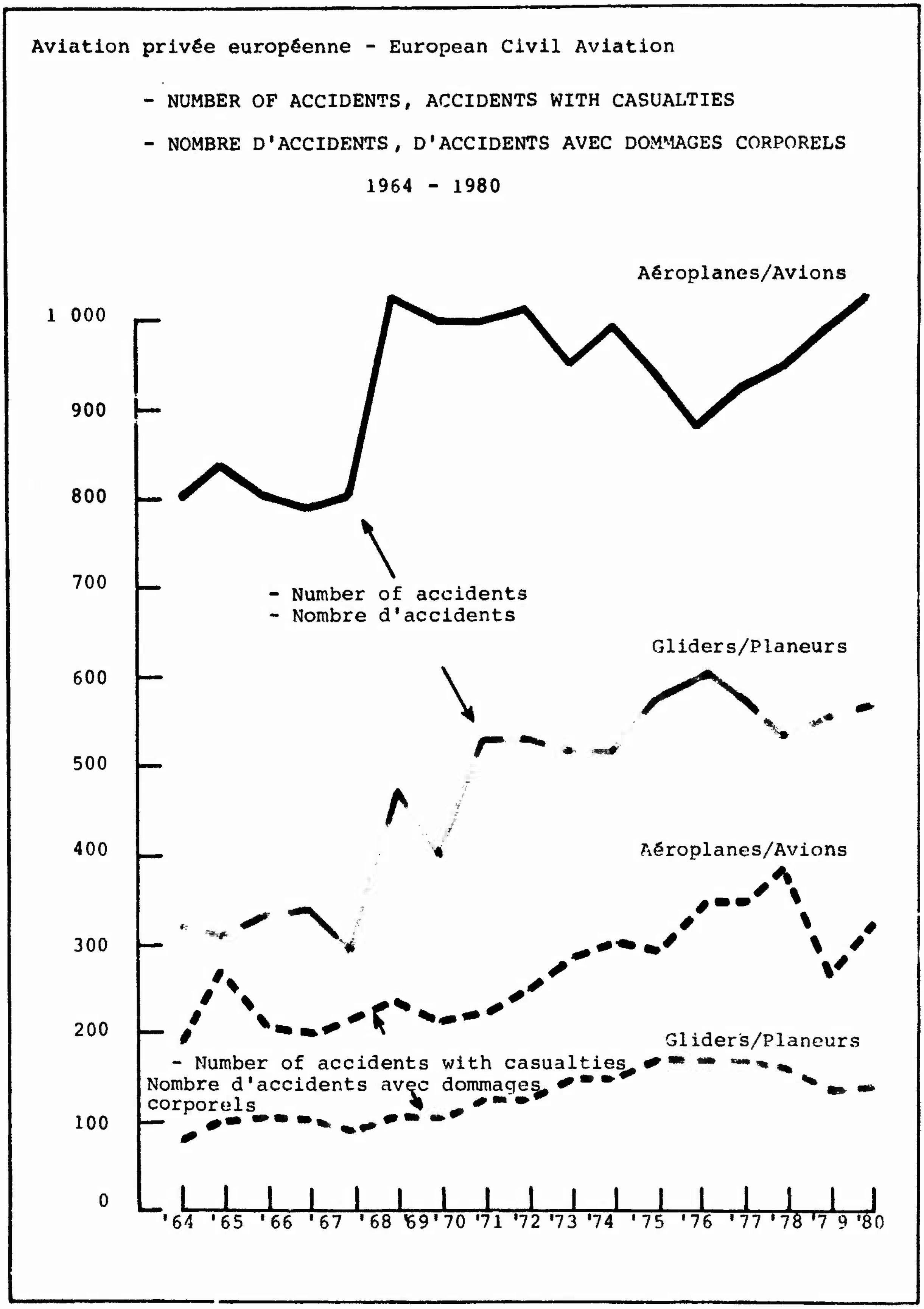
1964 - 1980



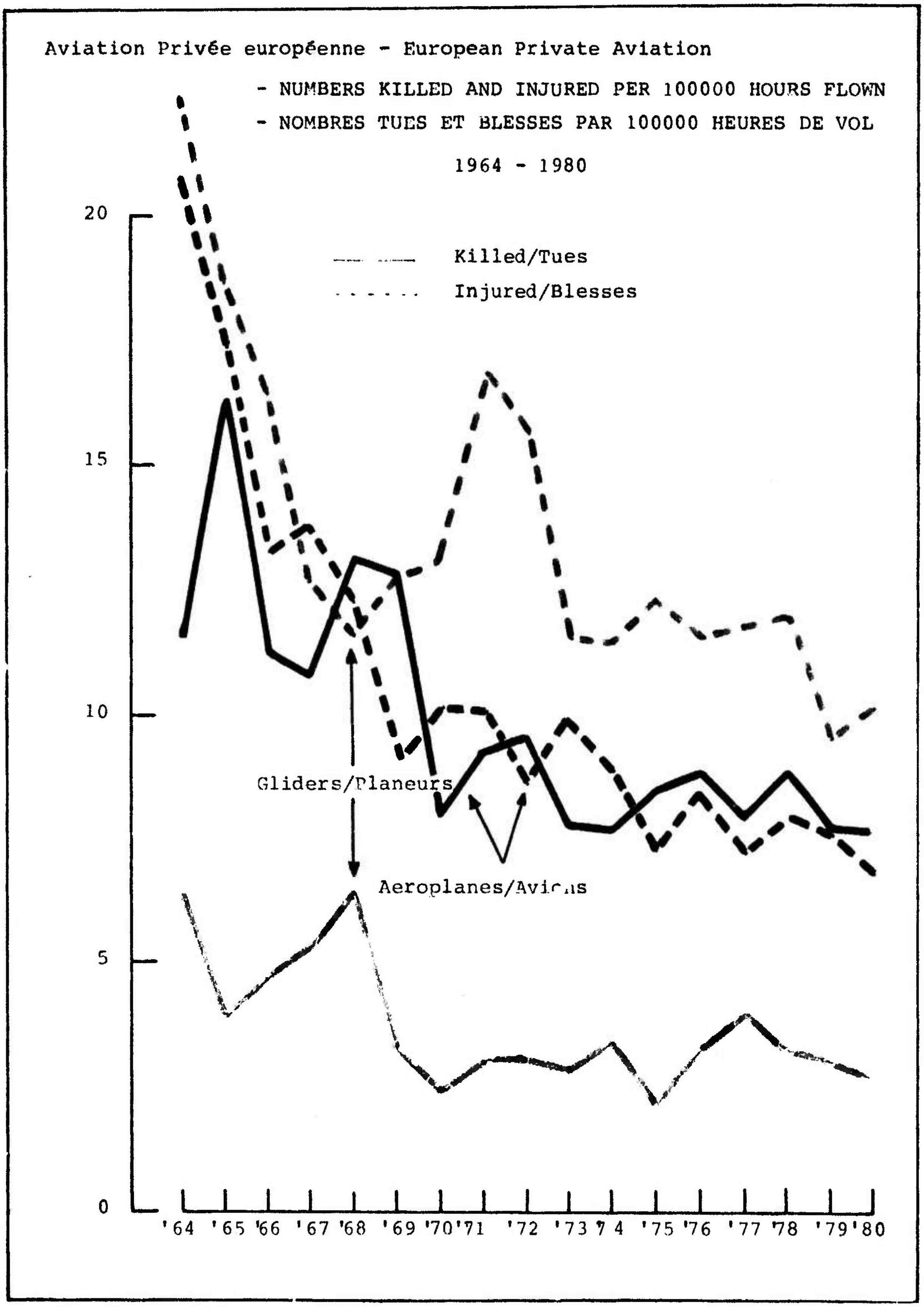

Diapositive 16




Diapositive 17




Diapositive 18




Diapositive 19

# THE INFLUENCE OF HANDLING QUALITIES, CRASHWORTHINESS, AND OTHER ENGINEERING FACTORS ON AIRCRAFT SAFETY

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SUMMARY

From the early days of aircraft flight, handling qualities have had an important effect on aircraft safety. The growth of aviation has been slowed by poor handling qualities in areas such as stall/spin, static and dynamic instabilities, and inadequate flight path control. The crashworthiness and pilot survivability in a forced landing depend a great deal on accurate control in an emergency situation. Military handling qualities specifications have attempted to include safety aspects by limiting degradation of handling qualities for various system failures.

Experience has shown that accidents are more likely to occur when the pilot is given deficient handling qualities. Gaps exist in the military handling qualities specifications because of the difficulty of establishing realistic limits which could compromise mission effectiveness.

## 1. INTRODUCTION

Most of us can appreciate that good aircraft handling qualities are necessary to realize the overall performance capabilities of an aircraft. Without good handling qualities it would be necessary to restrict operational use of an aircraft because of the pilot's inability to accurately control flight path, and mission effectiveness would be compromised. It may not be as apparent, however, how handling qualities also affect safety and survivability of the pilot. For example, an aircraft which rolls abruptly at the stall with no warning would be less safe to operate into short fields. If the stall occurs in the approach, crew survivability may be questionable because of insufficient altitude to recover to a wings-level attitude which would improve crashworthiness aspects.

Because of the ever-expanding flight envelopes of current and future aircraft, adequate inherent aerodynamic stability and damping are not easily obtainable, and more dependence is being placed on stability and control augmentation systems, thereby raising a safety question in the event of systems failures. Early studies (Ref. 1) of a pilot's ability to control during stability augmentation system (SAS) failure indicated that an appreciable transition time is needed to adapt to an SAS failure, and control of flight path could be lost if the basic vehicle dynamics are poor. Higher performance aircraft requiring increased control-system complexity have therefore had to face the problem of systems failures in a realistic and cost-effective manner.

From the beginning, military handling qualities specifications have attempted to include safety aspects by limiting degradation in handling qualities for various failure states, with primary emphasis on mission accomplishment. As noted in the Background and User Guide for M-F-87858 (ASG) (Ref. 2), while survivability is an important consideration, it has not been possible to relate any specific handling qualities requirements to this aspect.

There is a need to examine the factors involved in establishing levels of handling qualities for the various parts of the flight envelope to obtain a clearer understanding of safety and survivability requirements. In this regard, there are two important considerations. One is that there are many tradeoffs involved in obtaining safety; a very safe airplane may lack performance and not be competitive. The other is that realistic safe limits of handling qualities are exceedingly difficult to establish. To set meaningful limits in flight, even with variable stability and control aircraft, has proved to be dangerous at the extremes of the flight envelope. Piloted simulators can be very helpful with due consideration for limitations in realism because of finite motion restrictions and lack of real-life visual cues.

Some light may be shed on the subject by examining how handling qualities characteristics bear on safety and survivability from the history of experience with different aircraft. An AGARD Symposium in 1970 (Ref. 3) served to focus attention on learning from past experience in accidents and incidents, although handling qualities per se were not examined from safety, crashworthiness, and survivability standpoints. It is not possible to make a systematic investigation of all safety problems, but merely to review several pertinent examples.

The purpose of this paper is to examine the relationship of handling qualities to safety, crashworthiness, and survivability with the following guidelines:

- Point out which handling qualities are of greatest concern
- Discuss gaps in knowledge
- Help define methods to improve flight safety

The scope of the presentation will include the following: (1) a brief discussion of the philosophy used in the military specifications for treatment of degraded handling qualities, (2) an examination of several example handling qualities problem areas which influence safety, and (3) a movie, slides, and viewgraphs are used to illustrate the potential dangers of inadequate handling qualities features.

## 2. RESULTS AND DISCUSSION

### 2.1 Military Handling Qualities Specifications Framework

In the following discussion, the structure of military handling qualities specifications, primarily those used by the U.S.A. (Ref. 4) and U.K. (Ref. 5), are reviewed briefly to indicate the degree to which safety and survivability are included in setting up specifications for piloted aircraft. First, it is necessary to understand the purpose or use of the specifications as contained in Ref. 4, p. 58.

"Intended Use. This specification contains the flying qualities requirements for piloted airplanes and forms one of the bases for determination by the procuring activity of airplane acceptability. The specification serves as design requirements and as criteria for use in stability and control calculations, analysis of wind-tunnel test results, flying qualities simulation tests, and flight testing and evaluation. The requirements are intended to assure adequate flying qualities regardless of design implementation of flight control system mechanization. To the extent possible, this specification should be met by providing an inherently good basic airframe. Where that is not entirely feasible, or where inordinate penalties would result, a mechanism is provided herein to assure that the flight safety, flying qualities, and reliability aspects of dependence on stability augmentation and other forms of system complication will be considered fully."

### 2.2 Levels of Flying Qualities

The primary manner in which the military specifications indirectly account for flight safety is by stating the handling qualities requirements in three levels. These are noted as follows:

- Level 1 - Flying qualities clearly adequate for the mission Flight Phase
- Level 2 - Flying qualities adequate to accomplish the mission Flight Phase, but some increase in pilot workload or degradation in mission effectiveness, or both
- Level 3 - Flying qualities such that the aircraft can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both

Thus, it can be inferred that the aircraft can always be flown safely, since operation below Level 3 is not permitted. Unfortunately, the evaluation upon which the requirements are based was obtained with only one "bad" value of handling qualities. Indications are, however, that combined degradation of two or more factors can be significantly worse than degradation by any one parameter alone. There are too little data to treat the problem adequately; however, some confidence of success is gained by including probability of failures. Limited degradation of handling qualities (e.g., Level 1 to Level 2) is acceptable if the combined probability of degradation is small. If the probability of failure is high, then no degradation of handling qualities is allowed.

There is, of course, a direct association between the three levels of acceptability and the currently used Cooper-Harper pilot rating scale. This, in turn, provides at least a qualitative means of relating handling qualities to safety, since, for example, a high rating of 10 implies all control is lost, and a safe landing cannot be effected.

The U.K. and French handling qualities specifications tend to follow those of the U.S.A. Clearly, additional effort is needed to define more directly how values of handling qualities can make for safer aircraft, particularly since cost-effectiveness must be an important consideration.

### 2.3 Handling Qualities Problem Areas

In the following paragraphs, aircraft operating experience is reviewed to illustrate how aircraft handling qualities can be responsible for unsafe operation. The aircraft include both conventional and V/STOL types. The main points to be made are whether adequate handling qualities requirements are at hand and to outline where future research is needed.

2.3.1 Control Power. Control power is the one handling item that can set the boundary of the operational flight envelope for any type of aircraft. The importance of the need for adequate control power is clearly demonstrated in operation of V/STOL aircraft where only minimum values of control power are supplied because of the adverse effect on performance when the propulsion system must generate vertical lift as well as control forces. Flight experience with a wide variety of V/STOL aircraft has shown that control about the roll axis has been more critical for safety reasons than for any other axis. Many of the various V/STOL aircraft flown have been involved in accidents or incidents due primarily to roll-control power problems. This is because V/STOL operation requires quick, precise, bank angle control for lateral positioning, for counteracting the effect of crosswinds in approach and landing, and for minimizing height loss in hover. The total roll control power depends on many factors, the details of which are discussed in Ref. 6. Of immediate interest for this discussion are the following major requirements for roll control:

- Control needed for upset (due to gusts, recirculation, ground effect, etc.)
- Control needed for timing
- Control needed for maneuvering

Of the foregoing, the amount of control power required for maneuvering is the primary item defined in the military specifications. The amount of control needed to counteract upset due to gust air and self-induced flow effects in ground proximity has proved to be one of the major reasons for increased demands for roll control power for most V/STOL aircraft. An example of this problem is discussed in Ref. 7. These flight test studies of the Bell X-14B jet-lift VTOL aircraft, shown in Fig. 1, indicated that of the total amount of roll control power available (approximately 1.0 rad/sec$^2$ angular acceleration), 60 percent (0.6 rad/sec$^2$) was required just to fly the aircraft in and out of ground effect on a calm day. It is noteworthy that this

aircraft was damaged in hover operation on four separate occasions, primarily because of inadequate roll control power. These accidents occurred because it was not possible for the pilot to correct for lateral side drift or maintain a wings-level attitude at touchdown in the presence of ground disturbances. In none of the incidents was the pilot injured. Primarily because of the low altitude used in hover (approximately 10 feet), the cockpit accelerations experienced at touchdown were small, and crashworthiness of the structure was sufficient to prevent pilot injury.

The X-14 aircraft was not equipped with an ejection seat. This raises an interesting question on survivability when the pilot must stay with the aircraft because of no escape possibilities. As noted in the following discussion, an escape means is not always a guarantee for success.

In carrying out a transition from conventional to powered-lift flight, a fatal accident occurred with the XV-5 fan-in-wing VTOL aircraft shown in Fig. 2. The item related to handling qualities in this example was the pitch trim change which occurred with configuration and airspeed changes. For an unknown reason, the pilot actuated the CTOL/VTOL mode selection switch which preprogrammed the horizontal stabilizer to a leading-edge-up setting at too high an airspeed. The resulting nose-down pitching moment could not be trimmed out by elevator deflection as the airplane proceeded toward the ground at a 45° nose-down attitude. The pilot ejected just prior to ground contact; however, the chute did not have time to inflate to arrest the relatively high sink rate. It is of interest to note that the accident would have been survivable had the pilot attempted his escape earlier. Undoubtedly, a compelling reason for staying with the aircraft was to try to regain pitch attitude control in view of a large audience of press and military personnel who had come to watch the novel performance capabilities of this VTOL concept.

In another case, a fatal hover landing accident occurred with another XV-5A aircraft due to foreign object damage (F.O.D.) in one of the lift fans. Because of loss of roll (attitude) control, the pilot elected to eject just as the aircraft hit the ground. Escape was not successful because the angular accelerations imposed on the seat mechanism at touchdown tilted the seat trajectory away from the vertical so that the chute was not fully deployed. An inspection of the wreckage indicated that the accident would have been survivable had the pilot elected to stay with the aircraft. Had the pilot appreciated the crashworthiness of the fuselage structure, he may not have elected to use the ejection seat.

A point for discussion is whether the VTOL handling qualities specifications adequately cover the pilots' needs for control. The U.S. VTOL military specifications (Ref. 8) do not delineate specific values of control power for trim or upset, although AGARD Report 577 (Ref. 6) does. For a degraded system, a reduction in roll control power to approximately one-half of that required for normal operation is given in Ref. 8. Unfortunately, it is very difficult to determine from flight tests whether safe operation can be assured with a degraded system. A piloted motion-simulator study (Ref. 9) indicated that substantially larger values of control power are required for safe operation with a degraded control system. At present, the specifications are based on very limited operational experience and certainly do not reflect IFR night operation in atmospheric turbulence. Until more data can be gathered and analyzed, a realistic approach to roll-control power requirements for V/STOL aircraft cannot be achieved. Therefore, caution should be exercised in carrying out flight tests with new concepts, since, as noted by the foregoing and in the following paragraphs, experience has indicated some lack of success in these areas.

2.3.2 Positive Dihedral Effect and Yaw-Roll Cross-Coupling. One of the most critical requirements for roll control power for V/STOL aircraft in low speed flight has been that needed to trim in sideward/sideslip flight and yawing maneuvers. The apparent dihedral effect (roll moment due to sideslip) differs for each VTOL concept because of the difference in magnitude of rolling moment introduced from both aerodynamic- and engine-induced flow sources. This condition can be generated even in hover operation by turning out of a headwind or by making wings-level (skidding) turns in air taxiing. The dire consequences of excessive yaw-roll cross-coupling have been sadly overlooked in flight testing such VTOL aircraft as the Balzac, Mirage III-V, SC-1, P-1127, Harrier, and XV-5A, all of which have been damaged in accidents. Adding to the severity of the problem is the fact that the pilot may not instinctively apply the correct control input to reduce the roll excursion. For example, use of the roll control to reduce the bank angle divergence resulting from the positive dihedral effect generated in a skidding turn may only serve to aggravate the situation because of adverse yawing moment generated by aileron deflection. The problem can be very serious because of the lack of warning and short adaptation time available. Rudder control would be more effective in controlling the roll off by reducing sideslip.

The V/STOL military specifications requirement (Ref. 8) places a limit on positive dihedral effect by stating that no more than 50 percent of the roll control power available to the pilot should be required for sideslip angles which might be experienced in service employment. Although the intent of this requirement is to provide some maneuvering capability during crosswind operation, there are several deficiencies in this requirement. First, there are no allowances for control systems failures. Second, an arbitrary value of 50 percent roll control margin may not, in fact, adequately protect against sudden maneuvers such as turning out of a strong headwind. Finally, no provision is made to warn the pilot of impending disaster. A warning margin similar to that required in conventional stall approaches may be needed, since the loss in altitude due to an upset close to the ground is as serious as that resulting from stalling the wing. A warning system has, in fact, been added to the rudder pedals of the Harrier to aid the pilot's response to suppress sideslip. The significance of the need for a warning requirement was brought out by a fatal accident to a USAF pilot flying a Harrier. In this case, a skidding turn was made at approximately 90 knots where directional stability was insufficient to keep sideslip small so that the rolling moment could be offset by aileron control. The aircraft banked over 90° in about 2 seconds before the pilot elected to escape. Survivability can be marginal with this type of handling qualities deficiency because the aircraft will strike the ground in a wing down attitude. In this case the pilot was unwilling to accept that he had lost control of roll attitude (he had applied full aileron deflection against the roll).

2.3.3 Longitudinal Static Stability. Historically, handling qualities specifications have required positive static stability to prevent divergences in airspeed and angle of attack which, if undetected by the pilot, could result in an unsafe flight situation by not having sufficient control available for recovery. When an unstable variation of pitch control surface with airspeed is large, the aircraft may diverge (slow up) far enough from the trim speed to a point where even with the pitch control applied full nose-down, the airspeed could continue to decrease with catastrophic consequences if at low altitude.

A classic example of the potential danger of this situation occurred with an F-100 aircraft (shown in Fig. 3) during an attempted go-around at Edwards Air Force Base, California, in the 1950s. In this fatal accident, the pilot was attempting to land on a selected portion of the runway which had been surfaced with fire extinguisher foam to alleviate the effect of a misaligned nose wheel on touchdown. Because the pilot was unable to position the aircraft accurately over the foamed area on the runway (in part because of poor handling qualities at low speeds), he applied power to go around for another approach. Unfortunately, in his desire to land as slowly as possible, the aircraft was being operated on the backside of the power-required curve such that climbing flight could not be achieved even with full afterburner power. Both longitudinal and lateral directional control deteriorated irrevocably at low speed. The motions of the aircraft, classically known as the "Sabre Dance," dramatically portray the problem of safety and survivability when handling qualities deteriorate. Of special interest is the large nose-up attitude achieved in the go-around attempt. Although no data were available from the accident, flight test results from an F-100A (Ref. 10) indicate that pitch instability would be encountered for angles of attack greater than 20°. In addition to the problem of flying an unstable aircraft, the proximity of the ground, the poor forward visibility, and lack of nose-down control made it difficult for the pilot to achieve the correct angle of attack for go-around. His instinctive choice of adding thrust to accelerate out of the problem area cost him his life. Had he recognized the impending loss of control, he could have reduced power and landed (gear up) on the remaining 10,000 feet of runway.

The military specifications of Ref. 4 do not permit basic airframe instability except for approved Special Failure States when artificial stability is provided. Although aircraft which have attitude command or maneuver command types of SAS can be quite stable with respect to external disturbances, safety comparable to that of the stable basic aircraft must be sought for failure-state situations. Because the SAS may use large amounts of control for artificial stability, the relative authority and interactions of command, augmentation, and trim functions must be given careful consideration for safety and survivability reasons. Of special concern is the operation of V/STOL aircraft which use powered-lift for slow-speed flight. The current V/STOL U.S. military specifications (Ref. 8) do not address STOL operations per se, but do allow for degraded (failure) state conditions where (limited) static instability can occur.

The point to consider here is that for aircraft with high authority SAS, and particularly for the STOL types with more reliance on powered-lift, careful attention must be paid to assure safety and survivability not only during normal failure conditions, but also as a result of battle damage to the flight control system. Attitude divergences must not be so severe that pilot escape is compromised. The ability to maintain wings-level control even in a crash can greatly affect the crashworthiness of the aircraft.

2.3.4 Longitudinal (Pitch) Maneuvering Characteristics Related to PIO. Short-period natural frequency, short-period damping ratio, and stick force per g are the primary parameters which influence the pilot's opinion of the pitch maneuvering characteristics. With certain values and combinations of these parameters, pilot-induced oscillations (PIO) may occur. The PIO problem is of direct interest because of the potential danger to safety and survivability of the pilot when this type of instability is encountered. Historically, PIO has occurred since early flight days and is caused by the pilot phasing his control inputs to amplify, rather than attenuate, the aircraft's dynamic response. PIO, which is a divergent oscillation of the coupled pilot-aircraft system, has become a more serious problem by the increased emphasis on low-altitude, high-speed flight where even small changes in flight-path angle result in large structural loads.

There are many factors which determine the susceptibility of an aircraft to PIO, including the pitch short-period dynamics, control systems dynamics, feel system phasing, control force and motion gradients, and control system friction and lost motion. In Ref. 4, requirements have been established to prevent PIO; however, the problem is not well enough understood at the present time to guarantee that the PIO problem will be nonexistent in new designs. An unknown dominant factor influencing PIO is the pilot's internal gain as part of a servo system. It is beyond the scope of this paper to go into details of the various predictive techniques to avoid PIO. Instead, several examples of the PIO problem are reviewed in the following paragraphs to assess safety and survivability aspects.

One of the more classic PIO accidents occurred when a Navy pilot in an F-4 Navy aircraft attempted a speed record run at low altitude near Albuquerque, New Mexico, on May 18, 1961. The aircraft had attained a speed of approximately Mach 1.1, 200 ft above ground level, when the PIO resulted in structural breakup of the aircraft. From the record of the aircraft response shown in Fig. 4, the suddenness of the divergent motion can be appreciated. It can be seen that in a period of slightly less than 2 sec the aircraft reached 14 g and three oscillations occurred. Survivability in this case was virtually impossible because of the abruptness of the oscillation and the fact that the aircraft completely disintegrated and caught fire in the air.

Although the accident was investigated thoroughly and the factors conducive to the unintentional flight-path deviation were reasonably well understood, the exact reason why the pilot encountered the PIO was never completely answered. In a piloted motion-simulator study conducted after the accident, it was determined that for this flight condition, the tendency toward PIO was markedly increased if the elevator stick forces were not completely trimmed. In addition, the oscillations would damp out if the pilot relaxed his hold on the stick. In this regard, it was known that it was customary for the Navy pilot who flew the F-4 to hold approximately 20 lb push force in his practice high-speed, low-altitude runs to provide a nose-up safety margin in the event he was distracted and relaxed pressure on the control stick. Other possible reasons proposed for the PIO included loss of the pitch damper and the fact that the Mach trim compensator had failed, resulting in a requirement for the pilot to hold a pull force to keep from descending too close to the ground. In this event, it is understandable that the pilot could not relax his hold on the stick to alleviate the PIO tendency. For subsequent high-speed, low-altitude operation, pilots were warned to keep the aircraft trimmed, and no further performance restrictions were necessary for the F-4 aircraft.

Historically, studies have shown that of the possible causes of PIO, the use of bobweights has been a major contributor. Aircraft such as the A-4D-2 and T-38 had experienced PIO during their development cycle, requiring tailoring of the bobweight system to alleviate the problem. It is important to note, however, that with the current trend toward highly augmented aircraft with poor short-period damping of the basic airframe, particularly when operated at high altitudes, PIO problems could arise even without bobweights being employed. Complex SAS have a tendency to introduce higher order dynamics in the control response with the ever-lurking possibility of PIO.

Another item of possible concern is when a side controller is used instead of a center stick. Much less research has been conducted to optimize control characteristics for side controllers, with the possibility of PIO. This point is demonstrated by a recent fatal PIO accident on takeoff of a BD-5 jet aircraft (Fig. 5) which employs a side controller. In this case, the pilot was attempting his first flight and overcontrolled seriously enough to snap roll the aircraft inverted. Having flown the BD-5-J myself, I can appreciate how an overanxious pilot could encounter a PIO when in close proximity to the ground. The combination of light control forces (2 lb/g), lack of stick centering, and good dynamic response of the aircraft requires a short adaptation time — not much, perhaps only 5 sec — and many pilots have flown it without causing PIO. Again, the PIO can be alleviated by merely relaxing the pilot's grip on the controller.

Another more recent PIO example occurred with the YF-16 aircraft during initial flight trials in January 1974. In this case, the pilot was attempting to "feel out" the control response by raising the nose of the aircraft at high taxi speeds. Upon rotating to about 10° nose-up attitude at an airspeed somewhat in excess of 130 knots, the aircraft unexpectedly lifted off with a roll-off to the left. In correcting with a right-wing-down command, a series of oscillations occurred primarily in roll. A time history of the takeoff run (shown in Fig. 6) indicated that the PIO persisted for approximately 15 sec at a frequency less than 1 Hz. Relatively high roll rates were being commanded (approximately 50°/sec) resulting in both position and rate limiting of the control system. Due to the combination of very high pilot gain and the control system lag at the high input frequencies, the pilot's input commands were 180° out of phase with the aircraft response.

Because of the heading deviation which occurred during the run, the pilot elected to add intermediate power and go around rather than to try to steer the aircraft back to the runway. A shallow climb to the left was initiated and no further serious PIO problems occurred throughout the remainder of the short flight. No sideslip was noted by the pilot during the large-amplitude roll oscillations which the pilot judged were the most serious. It is interesting to note that once away from the ground the pilot decreased his gain to where no further lateral PIO problem developed. A special point of interest in this case is the fact that with the 100 percent authority fly-by-wire system used on the YF-16 aircraft, the aircraft control system gain was easily changed to alleviate any further PIO tendencies without sacrificing other desired aircraft characteristics.

Another aircraft which has experienced pitch PIO problems is the YF-12 shown in Fig. 6. This aircraft is of special interest because of its unusual configuration and high-performance capabilities. The PIO has been encountered during aerial refueling where the pilot must fly close to a tanker and maintain the position for several minutes. This task results in high pilot workload because it requires tight, precise, attitude control. Although the handling qualities of the YF-12 are generally considered to be good for the refueling task, the pilot can be disturbed initially by a bobbing (structural flexing) of the cockpit which triggers a coupled SAS and short-period pitch-structural mode. The interaction tendency increases with increases in fuel loading. For the most part, the amplitudes of the PIO have been small, with a frequency of approximately 1 cps, and during the early portion of refueling (lighter-weight condition), the PIO was considered to be only a minor annoyance. In a few instances, however, large control inputs and large-amplitude pitch (g) responses have been experienced. The PIO was triggered in one case by an overshoot (runway) in the longitudinal trim system. A time history of this PIO is shown in Fig. 7 where the pilot attempted corrective action to keep the aircraft from reaching a structural g limit. Note the rapid build-up in normal acceleration which persisted for several seconds.

An analysis of the longitudinal PIO tendencies of the YF-12 aircraft by Smith and Berry (Ref. 11) showed that the large-amplitude PIO can result from a rate limiting of the SAS and control position saturation, which, in turn, causes a phase lag and reduced damping. The potential safety problem if a large-amplitude PIO occurs is a possible collision with the tanker or structural breakup of the aircraft.

2.3.5 Lateral-Directional PIO (Roll Coupling). In general, experience has indicated that lateral-directional oscillations, although prevalent on many types of aircraft, have not proven to be quite as serious a problem from safety and survivability standpoints as longitudinal PIO. There have been some notable exceptions to this, however, and, because of the complex interaction of many factors which govern the lateral-directional behavior of an aircraft, there is no absolute assurance that future problems will not occur. The lateral PIO can occur in several forms including the classic Dutch-roll instability, a coupled roll-spiral mode, or a roll-coupled inertial oscillation. Key parameters which influence lateral-directional PIO are numerous and include the Dutch-roll frequency and damping, roll-mode time constant (roll damping), roll control sensitivity, control system dynamics, roll-spiral mode coupling, adverse yaw, directional stability, inertial (gyroscopic) characteristics, side force characteristics, and dihedral effect. In the interest of brevity, no complex analysis of the problem will be attempted, but a few flight experiences will be reviewed to serve as examples of where to focus attention for future improvements in safety and survivability.

The landing and takeoff flight regimes pose the greatest potential hazards for serious consequences of lateral-directional PIO. This is because altitude can be lost quite suddenly in an uncoordinated bank attitude, particularly for VTOL aircraft. High-altitude operation can also be a problem because of the reduced aerodynamic damping, and if the dynamic pressure is high, the structural limits of the aircraft can be reached easily in yaw maneuvers.

One early example of the lateral-directional PIO problem for VTOL aircraft occurred in a flight of the French Balzac delta wing, jet-lift/VTOL concept described in Ref. 12. This aircraft employed eight RB 108 turbojet engines in the fuselage for vertical flight, with a conventionally mounted Orpheus jet engine for cruise. This aircraft, in common with other jet-lift types, experienced a relatively large rolling moment with sideslip (positive dihedral effect) which in forward flight increased in severity with increase in angle of attack. Large dihedral effect in combination with low Dutch-roll damping, was the primary cause of a fatal accident while the pilot was attempting to enlarge the flight envelope by exploring the transition corridor. Large-amplitude roll oscillations occurred as a result of insufficient roll control power to counteract the rolling moment due to sideslip, and a large phase lag between pilot input and aircraft response persisted for several cycles. The aircraft motion was typical of a "falling leaf" maneuver in which altitude loss can occur more quickly for VTOL aircraft when the angle of bank exceeds 90° because the engine thrust now acts in an unfavorable (downward) direction. The pilot of the aircraft was outstanding in his ability to control VTOL aircraft, having flown the X-14 VSS aircraft with very low control power at Ames Research Center in 1963. He had almost damped the oscillation just as the aircraft struck the ground. Adding to the problem with VTOL

aircraft is the large magnitude of thrust tending to help overturn the aircraft on ground contact and crush the cockpit structure, thereby making survival more difficult.

The lesson to be learned here is that this type of lateral disturbance can be dangerous because the pilot believes he can damp the oscillation in the next cycle; unfortunately, because of the large (90°) bank angles attained, altitude is lost very rapidly, and the close ground proximity contributes to the pilot's overcontrolling tendencies.

Another form of lateral divergent oscillation, a coupled roll-spiral mode, can occur with a certain combination of lateral-directional aerodynamic parameters. This type of lateral PIO occurred on three occasions with the M2-F2 lifting-body vehicle (shown in Fig. 8) in the low-angle-of-attack, final approach, preflare situation. The oscillation on the last flight was severe enough to contribute to a gear-up landing in which the vehicle was extensively damaged and the pilot severely injured.

A systems analysis of the PIO reported in Ref. 13 was performed using predicted aerodynamic stability and control derivatives for the condition in which the PIO occurred. The formation of the coupled roll-spiral mode was attributed to the large effective dihedral, large positive yawing moment due to roll rate, low roll damping, and large adverse yawing moment due to aileron deflection. The situation was aggravated by coordinated use of the rudder when the pilot attempted to control bank angle precisely. A lower angle of attack increased the PIO because roll damping decreased.

A time history of the PIO is shown in Fig. 9. Note that the initial roll was due to sideslip and very large roll rates occurred. The pilot knew from simulator studies that it was possible to damp the oscillation by increasing the angle of attack. Even though control was regained prior to touchdown, the PIO, combined with the presence of a helicopter in the landing pattern, distracted the pilot so that he inadvertently forgot to extend the gear (which normally was extended just before touchdown in order to maximize L/D), and the aircraft tumbled end-over-end on the lake bed. The crashworthiness of the cockpit area was poor and the pilot received serious head injuries during the aircraft tumbling motions. The pilot's comments during the maneuver are interesting from the standpoint that even in spite of the large-magnitude PIO, safety and survivability were not mentioned (Ref. 13).

"I was well on my descent and picking up speed at very low angle of attack. In the final approach, as I went into the final turn, I wasn't getting the turn rate that I wanted so I turned the interconnect up to 0.45 and then continued the turn. I was well-established in my glide, very low angle of attack, picking up my airspeed, and had the feeling that I would land just slightly short of the 2-mile point, angling across the runway. Everything was going normally with no problems, then suddenly at 5000 to 7000 ft, with no warning at all, I experienced very high roll accelerations as a divergent Dutch roll-type of maneuver developed. Roll rates were extremely high and, from experience with high roll rate maneuvers in the F-100, I would say rates in excess of 220° per second. This maneuver was disorienting, and I pulled back on the stick to increase angle of attack, trying to damp it out. The first thing that entered my mind was that the interconnect was too high so, as soon as I was able to get hold of the situation, I checked my interconnect; it was 0.45, about where I wanted it. The corrective action of pulling back on the stick damped out the maneuver."

The M2-F2 vehicle was modified with an additional centrally located vertical fin and redesignated the M2-F3. With the center fin, the yawing moment due to aileron deflection became favorable, and no aileron-to-rudder interconnect was needed. The aircraft was sufficiently improved such that no serious roll-spiral mode coupling occurred, although some longitudinal PIO tendencies were noted in the landing approach.

The point to be made here is the significance of maintaining good handling qualities in the approach and landing phase. The possibility of encountering even short-term upsets close to the ground can be very distracting to the pilot and markedly influence safety. Being so close to landing, the pilot will generally try to land an aircraft with short-term, poor handling qualities by trying harder.

2.3.6 Roll-Pitch-Yaw (Inertial) Coupling. Another form of lateral-directional oscillation can be encountered during rolling pullout maneuvers commonly used in combat. The oscillation involves interactions among the airframe aerodynamics, the inertia characteristics about all axes, and the kinematics of the rolling motion. Of the several aircraft which have encountered inertial coupling, the case of the experimental Bell X-2, discussed in the following paragraph, is very dramatic (see Ref. 14) from the human factors standpoint.

The X-2 (shown in Fig. 10) was one of a series of high-speed research aircraft having performance capabilities exceeding a Mach number of 3 and an altitude potential of 126,000 ft. The wings were swept 40°, construction was of stainless steel, and the aircraft was powered by a rocket engine of 15,000-lb thrust.

The aircraft had been flown cautiously at high Mach numbers because of a known deterioration in directional stability at moderate angles of attack. On the last flight, a USAF pilot, flying the aircraft for the first time, attempted to set a new USAF speed record before the aircraft was to be turned over to NACA for flight testing. A time history of a portion of the fatal flight is shown in Fig. 11. After rocket burnout, control motions were initiated to start a left turn, and the angle of attack was increased. As the turn progressed, directional stability decreased, such that when corrective aileron deflection was applied to limit the left banking tendency (caused by the dihedral effect), the adverse yawing moment due to aileron exceeded the directional restoring moment due to sideslip. These motions increased in intensity until critical rolling velocity for inertial coupling was exceeded, at which time violent, uncontrollable motions occurred about all axes. High positive and negative accelerations were imposed on the aircraft, which finally entered into an inverted spin. The pilot made two recovery attempts, after which he jettisoned the escape nose capsule at a subsonic Mach number (altitude approximately 40,000 ft). The separation was successful; however, the capsule was violently unstable before the drogue chute was deployed. The pilot was incapacitated by the severe capsule motion and did not effect a separation from the capsule.

The lessons learned from this accident were threefold: (1) poor management was evident in allowing a first-time pilot to attempt a speed record in a hazardous environment; (2) the pilot had insufficient experience with the aircraft's handling qualities to maintain the necessary precise control of the trajectory at

high altitude; and (3) the pilot should have remained with the aircraft to lower altitude where increased angular rate damping would aid recovery from the inverted spin.

Current handling qualities requirements are designed to expose any inertial coupling problems by requiring rudder-fixed, full-aileron, deflection rolls through 360° at 80 percent of the limit load factor. One of the potential dangers of this maneuver is that the resulting oscillations can occur abruptly, and at high altitude where angular rate damping is low, the severity of the motions can disorient the pilot to compromise recovery techniques. The handling qualities needed to suppress this coupled behavior are positive directional stability at all obtainable angles of attack and minimum cross-coupling due to aileron deflection. Some current fighters limit the amount of aileron deflection obtainable at high speeds to alleviate this coupling problem.

2.3.7 Handling Qualities at High Angle of Attack. Recently, increased emphasis has been placed on the ability to fly safely at high angles of attack near stall to gain superiority in tactical operations for military aircraft. Good handling qualities are factors which are key to survival here, since out-of-control departures and spins can occur easily in these boundary conditions, and recovery for high-performance aircraft can often be very difficult. A variety of uncontrolled high-angle-of-attack dynamic phenomena have occurred. Two examples of general interest are the severe nose-slice (slew) departure characterized by a large, rapid yaw followed by a rapid roll as exhibited by the A-7 aircraft, and a wing rock encountered by the F-4 aircraft.

Analysis and simulation studies (Ref. 15) indicated that the nose-slice departure of the A-7 aircraft can occur at angles of attack considerably below normal stall. Aerodynamically, the nose slice is caused by vortices shed from the wing-fuselage juncture and downwind wing surface which impinges on the vertical tail to decrease directional stability. Directional mistrim or failure to minimize sideslip in approaching the stall gives rise to the yawing/rolling moments and nonlinear kinematic coupling. Pilot attempts to control (oppose the departure) can lead to a quick saturation of control in all axes. Lateral-directional control is apparently difficult to coordinate during the departure and recovery phases, and usually aggravates chances of recovery. If the initial departure is not immediately recognized by the pilots and they attempt to maintain control to higher angles of attack, eventually a more severe departure can occur, making the recovery more difficult and the altitude loss more dangerous from a survival standpoint. The best means of recovery is to pitch the aircraft down to reduce angle of attack.

Stalls departures and spins also occur for more modern fighters including the F-14, F-15, and F-16. If the F-14 is allowed to go through stall and into the departure and poststall gyration phases, the out-of-control flight, even under training conditions, can be traumatic even to the most experienced pilot. In a fully developed spin in an F-14, for example, not only are the "g" loads at the cockpit very high (6-g eyeballs out), but pilots can be disoriented such that they will have difficulty determining whether they are in an upright or inverted spin.

Needless to say, out-of-control recovery procedures must be well rehearsed both physically and mentally. The chances of recovery are very poor if the pilot is not fully prepared to execute the correct control motions in this stressful environment. In any emergency the flow of adrenaline quickens responses and time appears to expand. Tests have shown that under stress, time seems to expand by a factor of five. In a spin recovery, for example, the recovery procedure may require holding opposite rudder for 25 sec; however, to the stressed pilot, 5 sec seems like 25, thus compromising the chances of recovery.

The wing-rock departure exhibited by the F-4 can result in relatively large bank angle and sideslip excursions, with only small angle-of-attack oscillations. Wing rock appears to be caused or aggravated by pilot inputs and some slight (1° sideslip) asymmetry in yaw. Study of flight records indicates considerable roll control activity which interacts with destabilized lateral and longitudinal short-period dynamics. The resulting unstable Dutch-roll mode could be alleviated by releasing all controls.

The U.S. MIL-F-8785B (ASC) (Ref. 4) requirements for the stall characteristics do not allow uncontrollable rolling, yawing, or downward pitching at the stall in excess of 30° for fighter aircraft. These limits in divergence are obviously arbitrary and only indirectly relate to safety and survivability. A key problem is that if the primary task is tracking an enemy aircraft and the pursuing aircraft encounters a stall departure, tracking deteriorates and the primary mission must be abandoned. Although not addressed in the specifications, a Level-3 handling qualities condition has been reached, and the question of how much of the maneuvering potential of an aircraft must be traded for safety is very difficult to answer.

2.3.8 Flight-Path Stability and Control. The most serious operational problems which involve flight-path stability and control occur in carrier landings. In the interest of achieving maximum performance, approaches must be made on the backside of the drag curve where many factors interact to degrade operational success. The fact that the landing accident rate for naval aircraft in carrier landings is at least 10 times that for field landings points out the concern needed for safety and survivability.

Many studies have been made to define where major improvements can be made. As summarized in Ref. 16, the following areas are considered to have potential for major improvement:

- Improved flight-path control
- Decreased response to turbulence
- Reduced approach speed

Although all of the aforementioned factors are important in reducing accidents, flight-path control is, in the end, the key area for successful operations. As noted, operation on the backside of the drag curve, which is used routinely, is an unstable operation during which airspeed control tracking accuracy can deteriorate disastrously. The specifications of Ref. 4 attempt to place limits on the degree of backside operation allowed for different levels of flight conditions. Unfortunately, the situation cannot be solved by meeting only the backside requirements, since other items such as the longitudinal short-period dynamics, engine-thrust response, lateral-directional control, susceptibility to upsets by carrier-generated turbulence, etc., have

a profound influence. Carrier operations require accurate attitude and touchdown control; merely touching down on the deck is no guarantee for survival.

No attempt will be made here to pick out specific examples of aircraft which have had poor landing/survivability records, partly because there are so many. Rather, a brief discussion of certain handling qualities which are most important will be made.

A successful carrier landing requires precise control of the approach path, since, in the end, this will ensure that the aircraft catches the correct arresting wire on the deck. Contributing to the problem of obtaining precise flight-path control for current aircraft is a general tendency toward sluggish pitch response, a low normal acceleration response with increase in angle of attack, an initial loss in lift with pitch control deflection (due to the short-coupled features of current aircraft), and poor thrust response of large turbo-fan engines. Additional problems which affect safety include turbulence generated by the carrier wake, requirements to operate IFR in adverse atmospheric conditions, and the general tendency toward increased approach speeds. Lower approach speeds allow more time for the pilot to make corrections and reduce kinetic energy to increase survivability.

Means for improving the aforementioned deficiencies in modern carrier aircraft include high-order SAS to provide pitch response quickening, use of direct-lift control (DLC) to improve height control, and approach power compensators (APC) to alleviate problems caused by slow engine response. These features undoubtedly improve flight-path control precision; however, there are no specific requirements in the military specifications to cover the failure-mode conditions for this area. Since safety is directly related to good handling qualities in low-altitude operation of carrier approaches, clearly, improved requirements are needed.

## 3. CONCLUDING REMARKS

An examination of the relationship of aircraft handling qualities to safety, crashworthiness, and other engineering factors has shown that accidents are more likely to occur when the pilot has to cope with poor handling qualities. Most serious are deficiencies in roll control power, dihedral effect, yaw-roll cross-coupling, static and dynamic pitch instabilities, stall (high angle of attack departures), and flight path stability and control.

The current military specifications for handling qualities of piloted aircraft indirectly reflect safety by providing allowable levels of handling qualities degradation for system failures and by consideration of the probability of failure. Gaps exist in the specifications because it is very difficult to establish realistic limits in areas where safety and crashworthiness are of concern.

In spite of marked improvements in flight control technology, there is a continuing need to examine whether adequate stability and control features are being provided to permit the pilot to safely operate in the ever-expanding flight envelope of current and future aircraft. Emphasis should be placed on experience gained from incidents (and impending accidents) to provide insight for improved handling qualities requirements.

## REFERENCES


1. Sadoff, Melvin: A Study of a Pilot's Ability to Control During Simulated Stability Augmentation System Failures. NASA TN D-1552, Nov. 1962.

2. Chalk, C. R.; et al.: Background Information and User Guide for MIL-F-8785B (ASG) Military Specification - Flying Qualities for Piloted Airplanes. Tech. Report AFFDL-TR-69-72.

3. Anon.: Lessons With Emphasis on Flight Mechanics from Operating Experience, Incidents, and Accidents. AGARD Conference Proceedings No. 76-71. March 1971.

4. Anon.: Military Specifications Flying Qualities of Piloted Airplanes. MIL-F-8785B (ASG), Aug. 1969.

5. Bennett, G.: Revised Requirements for the Flying Qualities of Service Airplanes. Technical Memorandum Structures 863, April 1975.

6. Anon.: V/STOL Handling, II — Documentation. AGARD-R-577, Part II.

7. Anderson, Seth B.: A Discussion of the Use of Thrust for Control of VTOL Aircraft. Paper presented at the 31st AGARD Flight Mechanics Panel Meeting, Sept. 1967.

8. Anon.: Military Specification — Flying Qualities of Piloted V/STOL Aircraft MIL-F-83300, Dec. 1970.

9. Grief, Richard K.: Effect of Stabilization on VTOL Aircraft in Hovering Flight. NASA TN D-6900, Aug. 1972.

10. Quigley, Hervey C.; et al.: Flight Investigation of the Low-Speed Characteristics of a 45° Swept-Wing Fighter-Type Aircraft With Blowing BLC Applied to Trailing-Edge Flaps. NASA RM A58E05, Aug. 1958.

11. Smith, John W.; and Berry, Donald T.: Analysis of Longitudinal Piloted-Induced Oscillation Tendencies of YF-12 Aircraft. NASA TN D-7900, Feb. 1975.

12. Anon.: Military Applications of V/STOL Aircraft Vol. 1. AGARD Conference Proceedings No. 126, Oct. 1972.

13. Kempel, Robert W.: Analysis of a Coupled Roll-Spiral-Mode, Pilot-Induced Oscillation Experienced with the M2-F2 Lifting Body. NASA TN D-6496, Sept. 1971.

14. Day, Richard E.; and Reisert, Donald: Flight Behavior of the X-2 Research Airplane to a Mach Number of 3.20 and a Geometric Altitude of 126,000 Feet. NASA TM X-137, Sept. 1959.

15. Johnston, Donel E.; et al.: Investigation of Flying Qualities of Military Aircraft at High Angles of Attack. Vol. I. Technical Results. AFFDL-TR-74-61, June 1974.

16. A'Harrah, R. C.; and Siewert, R. F.: A Study of Terminal Flight Path Control in Carrier Landings. Report No. NA66H-289, North American Aviation, Inc., June 1966.

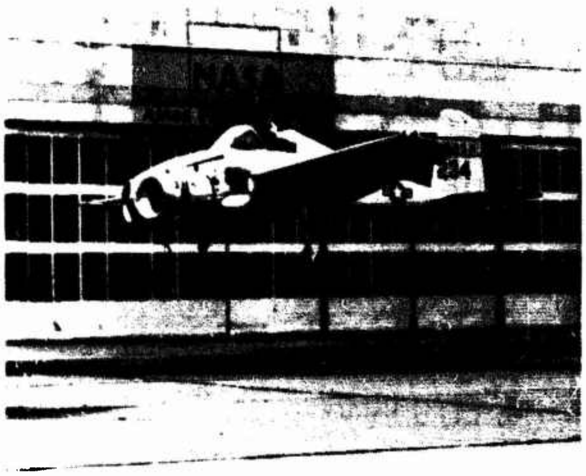

Fig. 1 Jet lift X-14A hovering.

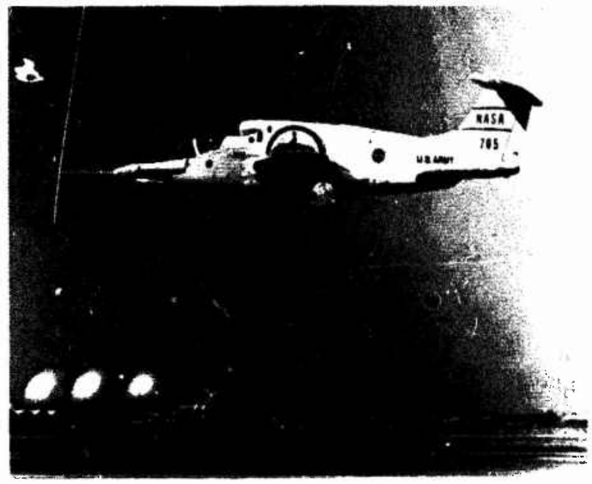


Fig. 2 Fan-in-wing XV-5B hovering.


Fig. 3 F-100 aircraft.

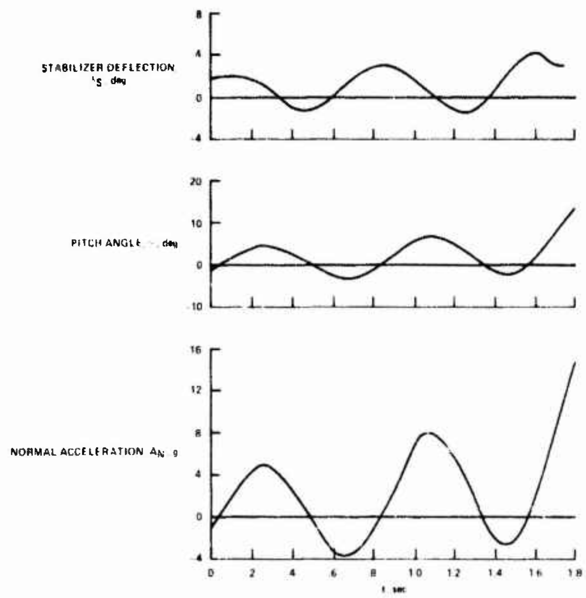


Fig. 4 Example of pitch LIP in high-speed low-altitude run.


Fig. 5 BL-5J in formation flight.

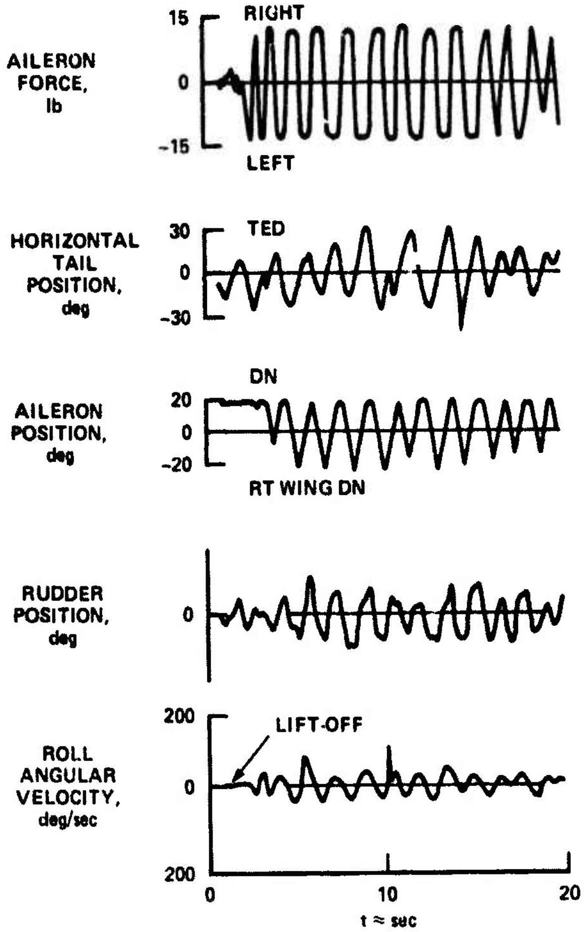


Fig. 6 YF-16 high-speed taxi test (first flight).

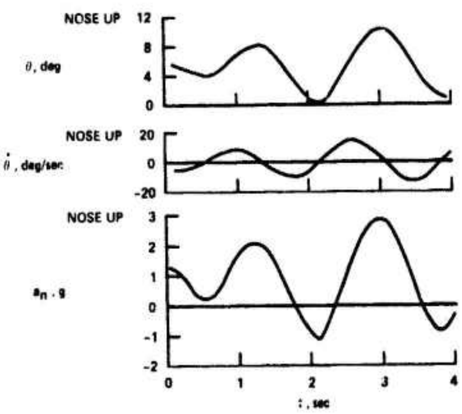


Fig. 7 PIO time history - YF-12 aircraft.

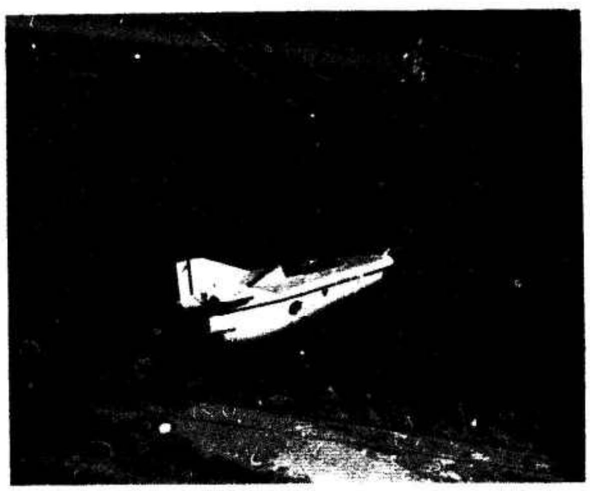

Fig. 8 M2-F2 lifting body.

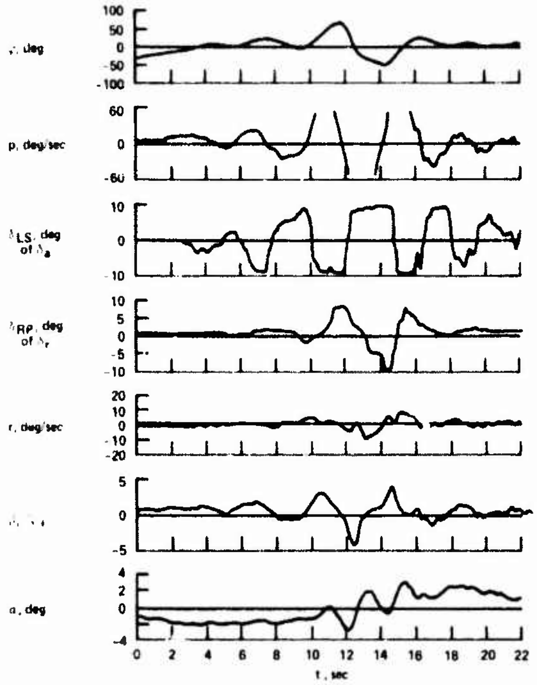

Fig. 9  Lateral-directional PIO — M2-F2.

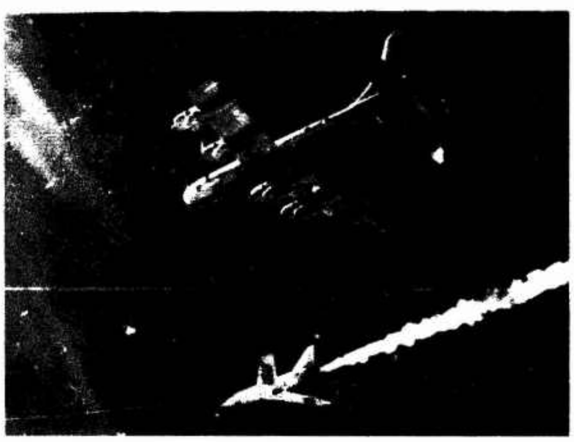

Fig. 10  X-2 research aircraft.

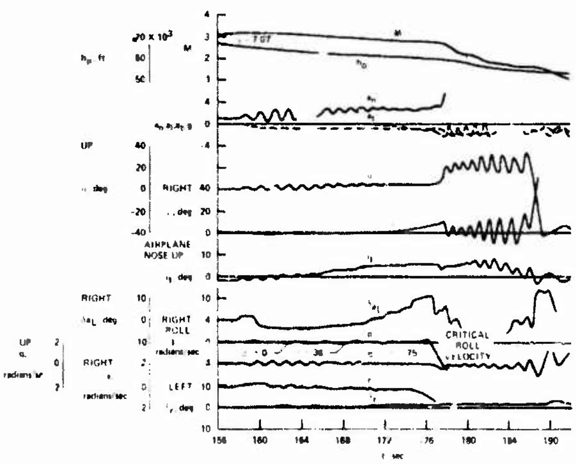

Fig. 11  Lateral-directional divergence — X-2 aircraft.

# A BRIEF REVIEW OF SELECTED AREAS OF AVIATION MEDICINE AND PHYSIOLOGY

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## SUMMARY

The purpose of this presentation ie to review avistion medicine and physiology with apecific focus on thoee aspects which relste to safety and accidents. Spacs limitstions dictata that only a small part of this field can bs covered in an incompleta fashion. Specific emphasis is given to the aeromedical aspects of ths effacte of altitude, tha accsleration environment, disorientation etreeees and visual function and problems in flight, as these arsas are felt to hsve most significant potential impact on flight safety. Ths presentstion is concludsd with a brief discussion of the common acute causes for grounding and sudden incapacitation which are of concern in military aviation.

## THE EFFECT OF ALTITUDE ON HUMAN PHYSIOLOGY

### Relevant Cheracteristics of tha Atmosphere

The charactsriatic of the atmosphere which is of primary interest in aviation phyeiology is the partial preasure of oxygen. Oxygen makes up approximately 21 percent by volume of dry air and this percentage remains constant during ascsnt to altitude. The reduction in total preasure on ascent is actually exponential; however, for the part of the curva that is of concern here (surface to 45,000'), this fall is reasonably linear (Figure 1). The alveolar oxygen tension ($PA_{O2}$) at esa level is approximately 103 mm Hg. It is ueeful to review the alveolar oxygen tsnsion at saversl other pointa slong this curve;

1. Fivs thousand feet - according to Ernsting (1) there are detectsbla degrsae of impairment, particularly to laarning, when brsathing air above 5,000'; thersfora, 5,000' ehould ba considered to be the altitude above which eupplemental oxygen is desireable; ($PA_{O2}$ = 75 mm Hg)

2. Eight thousand feet - the cabin sltitude maintained in many of the oldsr prssaurized traneport air-craft; ($PA_{O2}$ = 64 mm Hg)

3. Tan thousand fsst - the altituda abova which supplemental oxygen hss traditionally bean a rsquirement in military aviation; ($PA_{O2}$ = 58 mm Hg)

4. Eightasn thouaand feet - the altit-ude at which the barometric preesure and therafore, ths amount of oxygen available, has helved; ($PA_{O2}$ = 40 mm Hg)

5. Thirty-four thousand feet - the altitude at which when breathing 100 parcent oxygen the $PA_{O2}$ is roughly squivalant to the $PA_{O2}$ at sea level breething air; ($PA_{O2}$ = 103 mm Hg)

6. Forty-one Thousand feet - the altitude at which when breathing 100 parcent oxygen the $PA_{O2}$ ie roughly equivalent to braething air at 10,000'; ($PA_{O2}$ = 58 mm Hg)

7. Sixty-five thousand feet - the eltitude at which barometric pres-sure is equal to the vapor preesure of weter (PB 40 mm Hg); and theoretically, blood "boils." ($PA_{O2}$ = 0 mm Hg)

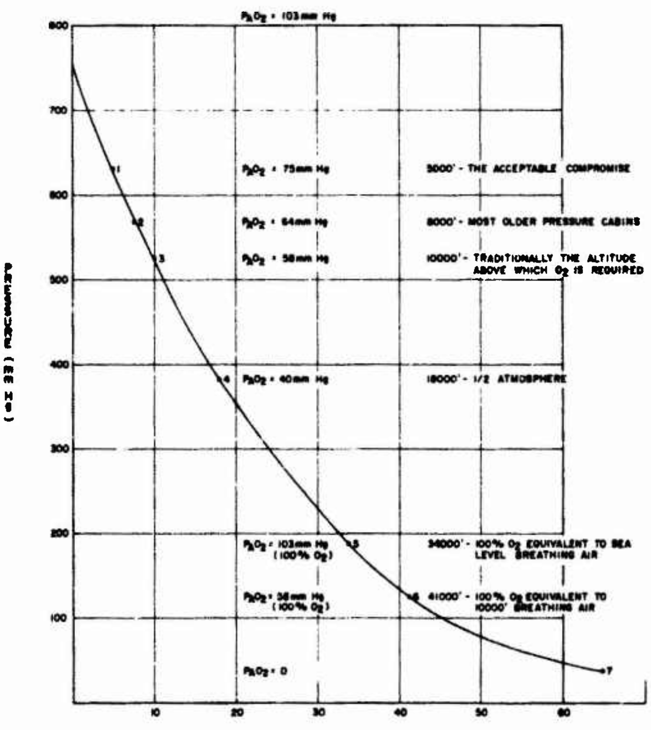


Figure 1. The relationship between stmosphere preesurs and altitude. The average slveolar oxygen tension ($PA_{O2}$) at selected altitudsa are shown.

Many of the older military transport aircraft are pressurized to around 8,000'. Furthermore, operational directives frequently allow military aircraft to fly to 10,000' cabin altitude before supplement oxygen is required. Occasionally, in order to fly higher, faster and conserve fuel this may be taken advantage of, and in some circumstances military aircraft are allowed to exceed 10,000' without supplement oxygen. It is now clear that cabin altitudes of 6,000 - 8,000' or more without supplemental oxygen result in an unacceptable degree of hypoxia which is a potential flight safety concern in some circumstances.

Physiological Response

Alveolar oxygen tension is directly related to the inspired oxygen tension; however, it is also significantly influenced by the neural porcesses which control breathing and the alveolar carbondioxide tension. This relationship is expressed by the alveolar gas equation:

$$PA_{O2} = PI_{O2} - PA_{CO2} \quad FI_{O2} + \frac{1-FI_{O2}}{R}$$

$PA_{O2}$ = alveolar oxygen tension

$PI_{O2}$ = inspired oxygen tension

$PA_{CO2}$ = alveolar carbondioxide tension

$FI_{O2}$ = fractional concentration of oxygen in the inspired gas

R = respiratory exchange ratio

At about 8,000 - 10,000 feet the hypoxic stimulus of the reduced arterial oxygen tension results in an increase in alveolar ventilation. The effective hyperventilation results in a fall in alveolar carbondioxide tension for any given altitude above 10,000'. The effect of this reflex stimulus to respiration on alveolar oxygen and carbondioxide tensions is shown in Figure 2. It is evident that this has a significant influence on alveolar oxygen tensions. There is considerable individual variation as a balance is struck between the hypoxic stimulus to respiration and the depressant effect on respiration of a reduced arterial carbondioxide tension. Even though the alveolar oxygen tension is markedly reduced despite this compensation, the characteristics of the oxygen dissociation curve are such that the oxygen delivered to the tissues remains adequate to maintain consciousness down to an arterial oxygen tension of about 40 mm Hg or an altitude equivalent of 16,000 to 18,000 feet. At the same time that the respiratory compensation is taking place, the initial cardiovascular response to hypoxia results in an increase in delivery of oxygen to the tissues per unit of time.

The compensatory respiratory changes invariably result in a mixture of physiological hyperventilation and hypoxia. The marked effect of the decreased carbondioxide tension due to hyperventilation on cerebral blood flow leads to a mixture of symptoms related to hypoxia and hyperventilation. These symptoms are widely variable both between and within individuals and they are markedly influenced by the rate of ascent, the altitude reached and the time at altitude.

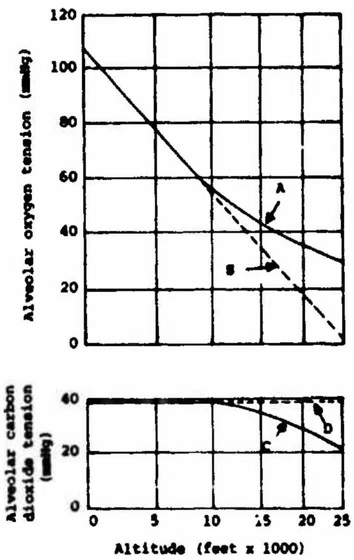


Figure 2. The hypoxic stimulus to respiration results in hyperventilation with lower than expected alveolar carbondioxide tensions (Curve C) and higher than expected alveolar oxygen tensions (Curve A) at altitudes above 10,000'.

Hyperventilation

Hyperventilation is a much more common condition than hypoxia (Figure 3). When hypoxia occurs, hyperventilation is usually associated; however, because of the tremendous reliability of oxygen systems and system checks, hypoxia is not common. Hyperventilation exists in any situation in which the pulmonary ventilation exceeds that required to eliminate the carbondioxide produced by metabolism. The effects of hyperventilation can almost all be attributed to the resultant respiratory alkalosis with consequent increase in the pH of the blood and tissues. This increase in pH profoundly reduces cerebral circulation as a result of vasocontriction. Peripherally, the increased pH results in decreased blood flow to the skin and increased sensitivity of nerve fibers resulting in numbness, tingling and tremor in the extremities. The reduced cerebral blood flow effectively produces or aggravates tissue hypoxia with corresponding alterations in consciousness. Unconsciousness and convulsions associated with hyperventilation are a very real complication and have been observed.

| | | |
|---|---|---|
| Hypoxia | | 1 - Ascent without 02 |
| | | 2 - Poor fitting mask |
| | | 2 - Lose of preesurization |
| | | 8 - Undetermined |
| | Total | 13 |
| Hypoxie/Hyperventiletion | | 3 - Undetermined |
| | Total | 3 |
| Hypervantiletion | | 10 - Anxiety |
| | | 13 - Undetermined |
| | Total | 23 |

Figure 3. Hypoxie and hyperventilation incidents with incepacitation in the Canadian Forces for the period 1964 - 1981 inclusive.

Ceuses of Hypoxia

Apart from the acceptable dagree of hypoxia which has baen previously described, hypoxia is likely to occur under three differant typas of circumstances:

1. Flight above 6 - 8,000' without pressurization or breathing oxygen - This could occur in oxygan equippad aircraft if thare was a failure to connect the supply or to turn on the supply. Howaver, most oxygen systems presently in use supply oxygen automatically when the mask/regulator connection is made and most mask/hoee assemblies will not operate unless a connection is made so thet this should not occur in oxygen equipped aircraft. This type of hypoxia is most commonly seen in unpressurized aircraft. It is most likely to result in e sub-ecute hypoxie with mild symptoms of insidious onset, since ascent is often slow end the altitude achieved moderete (10,000' to 15,000'). Headeche and fetique ere the commonest symptoms and decreased vigilance the commonest sign.

2. Failure of the oxygen delivery system - This may result in e slow onset of symptoms if the failure is incomplete. Howaver, if the feilure is complete, since this usually occurs in combat aircraft which ere capabla of high eltitudes end high rates of climb, the onset of symptoms is likely to be quite rapid. The outcome of thie type of incident depends upon the pilots ability to recognize the symptoms before becoming incepecitated. Oxygen systems are very simple and raliable and failures ere often the result of misuse or ebuse of the system. The most important factor in the prevention of this type of incident is scrupulous maintenance by ground crew and conscientious system checks by aircrew.

3. Feilure of pressurization - In this type of incident there is some potential for a slow onset of symptoms resulting from a slow decompression; however, decompression is usuelly quite obvious and descent can be made in time to maintain good oxygenetion. If the decompression is rapid, the eymptoms may also be repid unless emergency oxygen is immediately aveilable. The moet important factor in this type of incident is the ebility of tha crew to don properly functioning emergency oxygen equipment before becoming incapacitated.

Recovery from hypoxia is usually rapid and without sequelae. The most common after effect is a mild headache; however, there is e condition, described as the oxygen paredox, where symptoms may worsen end can result in convulsions on rastoration of the oxygen supply. Whether it is the oxygen paredox or not, recovery can be delayed for lengthy periods even after the restoretion of sdequate oxygenstion which may lead the investigator to attribute the incident to some other cause. Hyperventiletion end anxiety essocieted with tha incident may be contributing factors to the delayed recovery.

| CAUSE | NUMBER | SYMPTOMS |
|---|---|---|
| Regulator | 26 | 1 |
| System Misusa: | | |
| Aircrew | 7 | 3 |
| Groundcrew | 6 | 0 |
| Both | 8 | 1 |
| Undetarmined | 5 | 1 |
| Contamination | 2 | 0 |
| System Miscellanaous (Sourca, Guaga, Switch, Connactions, Etc.) | 18 | 1 |
| Total | 72 | 7 |

Figure 4. Oxygen system related incidents by cause fector in the Canadian Forces for the period 1974 - 1981 inclusive. Thoea incidents rasulting in physiological symptoms are noted.

While actual physiological incidents related to hypoxia are uncommon, oxygen system related incidents are not. The infrequency of resulting hypoxia attests to the ability of the aircrew to deal with the incident before incapacitation occurs. Figure 3 illustrates a breakdown of the hypoxia/hyperventilation incidents with incapacitation, by cause factor, in the Canadian Forces for the periods 1964 - 1981 inclusive. Figure 4 lists the oxygen system related incidents, with cause factors, for the periods 1974 - 1981 inclusive. During the eighteen year period 1964 - 1981 there were only thirteen incidents of incapacitation due to hypoxia compared to twenty-three incidents of incapacitation due to hyperventilation.

Prevention of Hypoxia Below 37,000 - 38,000 Feet

To maintain an alveolar oxygen tension equivalent to 5,000' breathing air, either the cabin has to be pressurized to an equivalent of 5,000' or the inspired oxygen fraction must be increased with supplemental oxygen to maintain an alveolar oxygen tension of 75 mm Hg. In order to do this, the inspired oxygen must be progressively increased to 100 percent at about 37,000' (Figure 5). To maintain alveolar oxygen tensions at this level above 37,000' - 38,000', pressure breathing will be required. Figure 6 illustrates typical

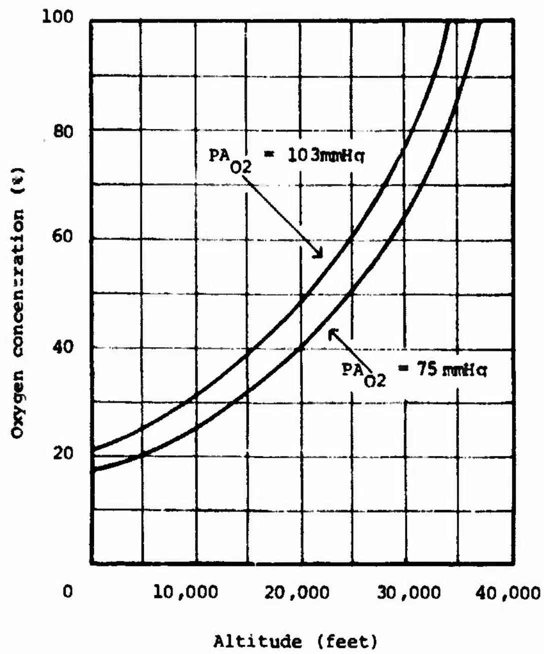


Figure 5. Curves showing the minimal oxygen concentration in the inspired gas required to maintain the alveolar oxygen tension at sea level equivalent ($PA_{O2}$ = 103 mm Hg) and 5,000' ASL equivalent ($PA_{O2}$ = 75 mm Hg)

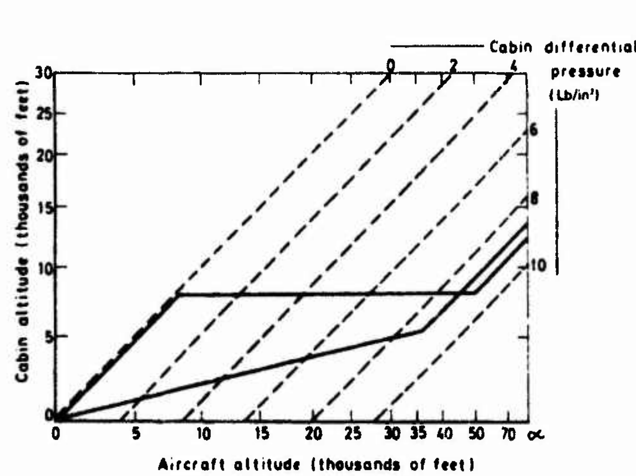


Figure 6. This illustrates two typical pressurization schedules for the high-differential pressure cabins found in transport aircraft.

pressurization schedules for the high differential pressure cabins found in transport aircraft. When the pressurization system is working, hypoxia is not a concern at normal operating altitudes. If the pressurization system fails, the key to the prevention of hypoxia is to descend the aircraft to a safe altitude before performance or consciousness is impaired. If the aircraft is operating above 30,000', even with a relatively slow loss of pressurization, there is likely to be an interval between the time of failure and the time that the aircraft reaches a safe altitude, during which supplemental oxygen must be supplied to the crew, and less importantly perhaps, to the passengers (Figure 7.) If the aircraft is above 30,000' and the pressurization loss is catastrophic, yet structural integrity of the aircraft is maintained, the cabin altitude may rapidly equal or even exceed the aircraft altitude due to aerodynamic suck (Figure 8). For the aircrew the "time of useful consciousness" now becomes an important factor and the surviveability of the decompression will very much depend upon the ability of the crew to rapidly don properly functioning oxygen equipment. For the passengers, surviveability will largely depend upon the rate at which the aircraft can be descended and the time that the cabin altitude remains above 14 - 15,000'. To prevent hypoxia in transport aircraft, therefore, emphasis should be on training for rapid decompression, donning of oxygen equipment and conducting an emergency descent.

For fighter aircraft which have a low differential pressurization schedule, as shown in Fiuure 9, the concern about the pressurization system up to altitudes of about 38,000' is less important than the concern about properly functioning oxygen equipment. The important factor is an oxygen system which supplies metered oxygen at an acceptable concentration. The concentration of oxygen in the inspired gas is dictated by logistical as well as physiological considerations. Obviously a simple solution would be to have a system which supplied 100 percent oxygen at all times. This would be effective in preventing hypoxia up to altitudes of 38,000 feet. However, one-hundred percent oxygen is logistically uneconomical and it has some negative physiological consequences, probably the most noteable of which is acceleration atelactesis. While acceleration atelactasis may be an irritation it is not usually a flight safety concern.

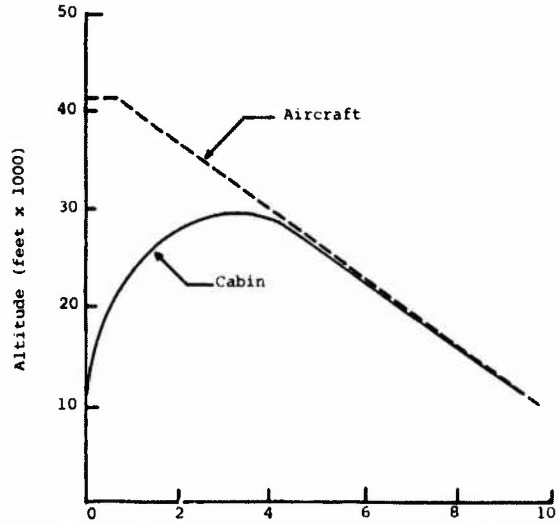


Figure 7. A possible time course for the cabin and aircraft altitudes following a slow but complete loss of pressurization in a transport aircraft. (Time in minutes)

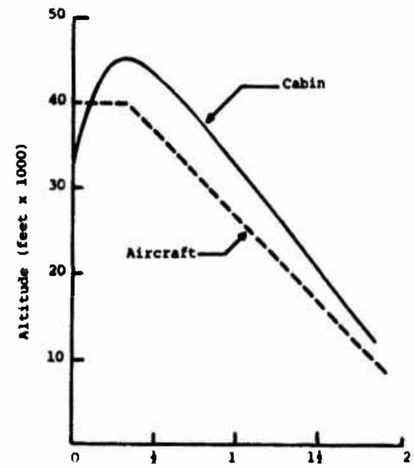


Figure 8. A possible time course for the cabin and aircraft altitudes following massive decompression. (Time in minutes)

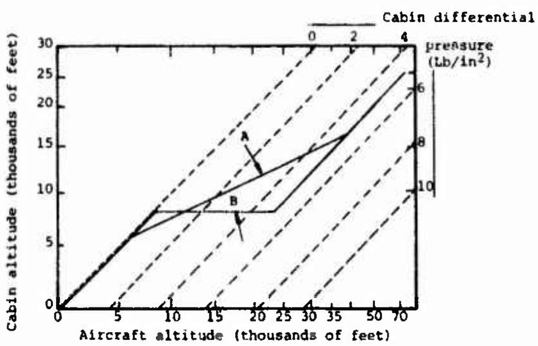


Figure 9. Typical pressurization profiles for the low differential pressure cabins found in combat aircraft.

| ALTITUDE (feet) | TIME IN SECONDS MEAN | STANDARD DEVIATION |
|---|---|---|
| 25,000 | 270 | 96 |
| 26,000 | 220 | 87 |
| 27,000 | 201 | 49 |
| 28,000 | 181 | 47 |
| 30,000 | 145 | 45 |
| 32,000 | 106 | 23 |
| 34,000 | 84 | 17 |
| 36,000 | 71 | 16 |

Figure 10. The time of useful consciousness in seated male subjects following a change from breathing oxygen to breathing air.

"Time of useful consciousness" (TUC) following decompression is obviously dependent on the rate of decompression and the final altitude reached. It is not so obvious that it is also dependent upon the initial cabin altitude and the composition of the gas being breathed immediately prior to the decompression. TUC is surprisingly long in subjects seated at altitude breathing oxygen who are suddenly subjected to breathing air, similiar to what might occur in a fighter cockpit in the event of decompression followed by oxygen system failure (Figure 10). TUC after decompression to 26,000' from breathing air at 8,000', as could occur in a pressurized transport aircraft, would likely be less than 30 seconds. At about 50,000', even with 100 percent pressurized oxygen prebreathing, TUC levels off at about 10 - 15 seconds and does not fall lower.

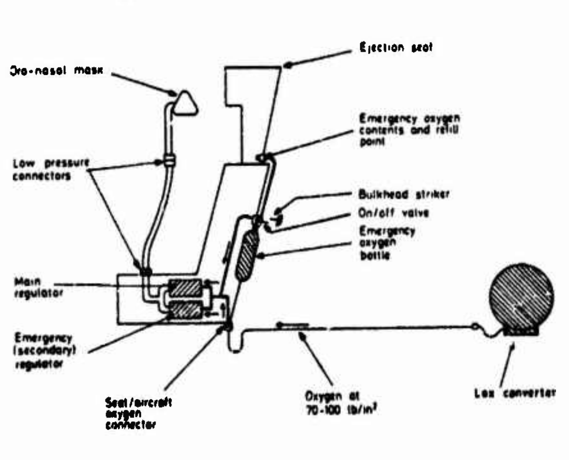


Figure 11. A schematic illustration of a typical liquid oxygen system that might be found in a modern ejection seat equipped combat aircraft.

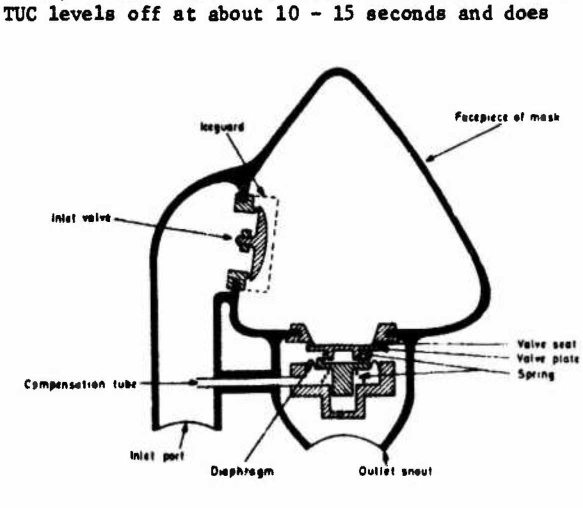


Figure 12. A schematic illustration of a typical pressure demand oro-nasal mask showing the valve assembly with a compensated exhalation valve.

A schematic illustration of a modern combat aircraft oxygen system is shown in Figure 11. Oxygen is matared through a diluter demand regulator according to s schedule which is designed to provide sufficient oxygen to maintain a satisfactory alveolar oxygen tension, with a ssfety factor. The design specificstion for some oldar systems calls for a supply of metered oxygen above 10,000' but most systems have a large safety factor and may bagin enriching tha inspired air even at sea level. Since a demand system only delivers oxygen on request of an inspiratory effort, there is potentisl for an inbosrd leak at the mask further diluting the inspired air. This can be pravented by s safety pressure mechanism which at altitudes where hypoxia may occur provides a low positive pressure in the mask so that any leaks should be outboard. It is obvious that the regulator, the fittings and the msek are the key elements in this system from the point of view of flight sefety. Failure of the oxygen source or of the regulator should be preventable with meticulous maintenance because of the simplicity and reliability of these systems. Figure 12 schematically illustrates a pressure demand oro-nasel mask. If there is a problem in the oxygen system, it is with this piece of equipment thst the problem often occurs, and it is frequently the result of misuse. The problems occur in the connections to the aircraft system, the hose, the fit of the mask to the face, and in the valve systems, most often the exhalation valve.

Conclusion

It is the flight surgeon's responsibility to teach aircrew; the circumstances under which hypoxia is likely to occur; the altitudes above which they need supplemental oxygen; the altitude above which they require pressure breathing; that any physiological symptoms experienced above 8,000' should be considered hypoxic until proven otherwise; that some action to ensure that they sre getting adequate oxygen is necessary treatment of these symptoms; that hyperventilation is ona of the commoneat causes of physiological symptoms in the air; and, that hyperventilation may exist with or without hypoxia. Aircrew who are adequstely grounded in these points of knowledge; who can recognize insidious and subtle degrees of impsirment; who sre suspicious of hypoxia as the ceusa of physiological symptoms; who are properly fitted with a good oro-nssal mssk; who daily "trouble ahoot" and maintain the serviceability of the mask; and, who have a "get me down" emergency system in the event of failure of the oxygen system or cabin pressurization, should fly ssfe from hypoxia below 38,000'.

## LONG DURATION $+G_z$ ACCELERATION

Definition

Acceleration is defined as a rate of change of velocity either in magnitude or in direction. It is therefore the second derivation of distance on time, and is expressed in units of distance and time (feet/sec/sec). For the purpose of this presentation, acceleration will be discussed using the unitless term "G". "G" is a dimensionless ratio describing the force that the pilot is subject to relative to the force of gravity.

$$"G" = \frac{\text{acceleration in cm/sec/sec}}{981 \text{ cm/sec/sec}}$$

This discussion will be concerned only with positive accelerations in the Z axis resulting from radial accelerstions which are experienced in combat aircraft during flight manoeuvring (Figure 13).

General Effects of $+G_z$ Acceleration

The first and most obvious effect of acceleration on a pilot is an impairment of his mobility. As aircraft have evolved with greater performance cspebilities it has become increasingly difficult for the pilot to mova while the aircraft is manoeuvring. In particular, it is virtually impossible for aircrew to exit e damaged or out of control sircraft at accalarations in excass of 2 - 2.5 $+G_z$. Consequently, tha pilot must be provided with an ejection seat so that at most he only has to move his arms and hands to tha ajection handles. Even this can be a concern; at accelerations in excess of 3 $+G_z$ it becomes increasingly difficult to lift the arms and hands and st sround 6 - 7 $+G_z$, it is almoet impossible to raise the hands to head level. In addition, it is extremaly difficult to turn the head or to extend the cervical spine at accelerations in excess of 4 - 5 $+G_z$. With tha additional weight of the helmet, if ths cervical spine is allowed to flex either laterally or forward at accelerations of 4 - 5 $+G_z$, it becomes very difficult to raturn the hsad to the neutral position. It is obvious that one of tha fsctors thst influencea this is the weight and positioning of the helmet and mask assembly and the effectiva displacament of the centre gravity of the hesd creatad by this life support equipment.

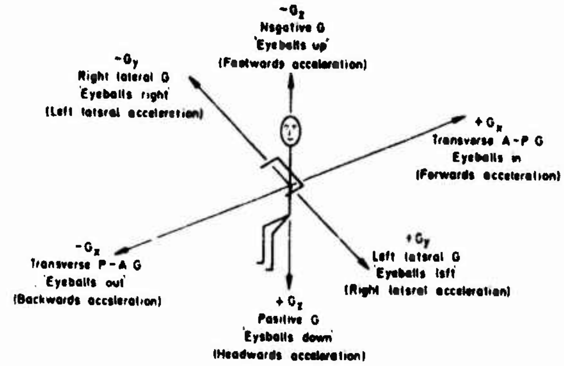


Figure 13. The standard AGARD terminology for the direction of sccelaration and inertisl forcee. The arrows indicate the direction of the resultant inertisl forces.

The next effect of positiva Z axis acceleration of concern to the pilot is its influence on vision. The first stage of visual impairment under $+G_z$ acceleration is called grayout. This term refers to a dimming of vision and loss of the peripheral field resulting in visual coneing or tunnel vision. Further increase in tha $+G_z$ acceleration may lsad to blackout with a total loss of vision. While unconsciousness and greyout/blsckout rasult from the sama physiological mechanism (reduced blood flow to the hesd), greyout/bleckout can exist without loss of consciousness. The "G" levels at which greyout and blackout occur vary significantly from individual to individual and alao within the individual from time to time. Symptoms of grayout or blackout may improve ssveral seconds after the onset of the accelerstion as the cardiovasculsr system begina to compenssta and voluntary "G" resisting measures are taken. If the acceleration stress is sufficiantly severa in magnituda or rata of onset or so prolonged that the individual cannot compensate,

he may become unconscious.

Acceleration induced loss of consciousness (LOC) is one of the major physiological flight safety concerns in fighter aircraft at the present time. Unconsciousness can occur without warning under conditions of rapid onset high $+G_z$. When unconsciousness does occur there is a complete loss of muscle tone usually followed by some tonic/clonic seizure-like activity due to cerebral hypoxia. This seizure-like activity can be very disturbing to a pilot who observes this in his co-pilot or to the inexperienced flight surgeon. However, the history is usually quite clear, and with an obvious cause, no investigation, apart from some concern for the pilots "G" tolerance is necessary. It is evident that if the acceleration continues under these circumstances, serious injury could occur to the individual. There is at least one incident recorded in the literature of neurological deficit following acceleration stress(2). The usual result, if the pilot blacks himself out, is that he loses muscle tone and the acceleration stress is thus relieved. When another pilot is flying the aircraft during high $+G_z$ manoeuvring, it is extremely important that the pilot in control continuously monitor the co-pilot or passenger so that any acceleration is immediately discontinued if the other occupant experiences blackout or becomes unconscious.

Recovery of consciousness after reduction of the acceleration stress may be followed by a period of confusion and there is often complete amnesia for the event. The time duration from the return of consciousness until the individual is fully oriented and able to effect a change in the condition of the aircraft may be as much as 30 seconds. For the pilot flying a single seat aircraft this may be sufficiently long to extend into eternity, and this has been the cause of a number of accidents. A high performance aircraft rolled inverted and allowed to enter a vertical dive at 35,000' can easily be in an unrecoverable dive in 15 seconds. In that the aircraft is not likely to be starting at 35,000' during air combat manoeuvring, the time element may be much less. Therefore, loss of consciousness due to rapid onset high sustained $+G_z$ is an extremely dangerous occurrence and the only solution from e flight safety point of view, is to prevent it from happening.

Physiological Effects of Long Duration Acceleration

The physiological processes which explain greyout, blackout, and unconsciousness, are relatively straight forward hemodynamic effects of acceleration on the cardiovascular system. These effects are illustrated in Figure 14. This Figure schematically illustrates the cerebral circulation and the retinal

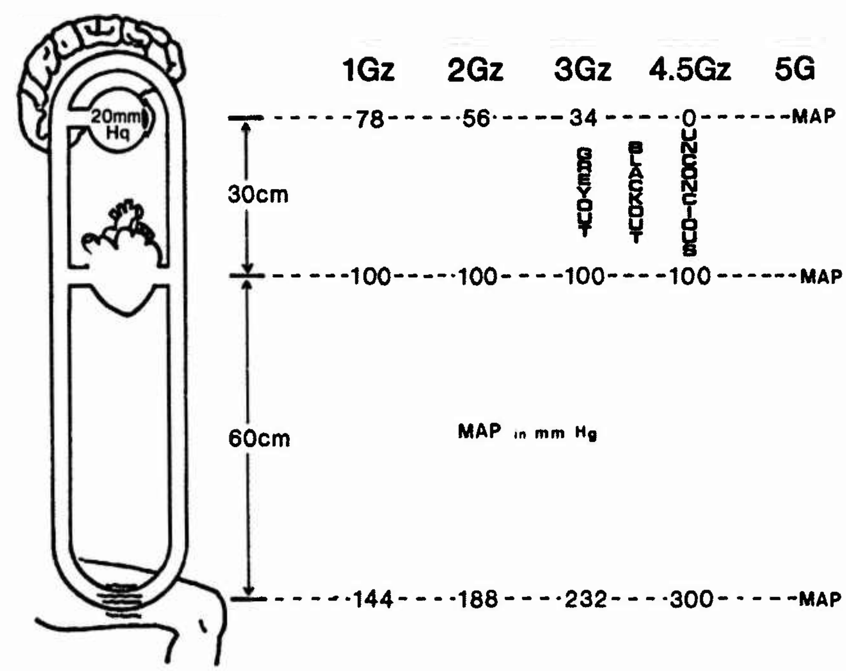


Figure 14. Schematic illustration of the influence of increasing $+G_z$ acceleration on mean arterial pressure (MAP) at head level, heart level and femoral artery level.

artery 30 cm above the heart, and the femoral artery 60 cm below the heart. It should be noted that the intraocular pressure is 20 mm Hg. Initially, for the purpose of this discussion, the cardiovascular system should be considered as if it were static and unresponsive to acceleration stress with the heart generating a mean arterial pressure (MAP) of 100 mm Hg. A column of blood 30 cm high exerts a pressure of 22 mm Hg, so that at eye level the MAP is reduced to 78 mm Hg and at the level of the femoral artery it is increased by a pressure equivalent to a column of blood 60 cm high (2 x 22 = 44 mm Hg), to 144 mm Hg. If the model is subjected to an acceleration stress of 2 $+G_z$, MAP falls a further 22 mm Hg at eye level and increases 44 mm Hg at the femoral artery; at $3+G_z$ MAP has fallen to 34 mm Hg at eye level and increased to 232 mm Hg at the femoral artery. At about $4.5+G_z$, MAP would fall to zero at eye level.

If tha cardiovascular system functioned in this manner, consider what would happen to vision and consciousness during exposure to this acceleration stress. With an intraocular pressure of 20 mm Hg, in order for blood to anter the eye it must reach eye level at something more than a pressure of 20 mm Hg. It is evident, therefore, that at about 3.5 $+G_z$ tha pilot is going to begin to greyout because there will not be sufficient arterial pressure at eye level for blood to perfuse tha retina. The retina has a very high matabolic rate and as soon as perfusion of the retina stops, it ceases to function and the pilot suffars from grey/blackout. It can ba clearly seen that the pilot can be suffering from blackout and still be conscious, because 20 mm Hg artarial pressure can adequately parfuse the brain so that the pilot still has a cerabral circulation when the circulation to the retina has stopped. Howaver, if acceleration is increased to 4.5 $+G_z$, MAP at tha carebral leval will fall to zero; theoretically blood should cease to flow through the brain and the pilot would than become unconscious within a few seconds. If the pilot suffered from grayout at 3 $+G_z$, blackout at 3.5 $+G_z$ and unconsciousnass at 4.5 $+G_z$, he would be in serious trouble in air combat.

Factors which Influence "G" Tolarance

"G" toleranca is influancad by such factors as; the coexistence of other stressas; individual physiological variations; the use of "G" rasisting techniques; the rate of onset and the duration; the use of tha "G" suit; and, selaction training and experience.

The coexistanca of many other physiological and psychological stressas potentially reduces the tolaranca to $+G_z$ stress. Fatiqua, anxiety, illness, hypoxia hyparventilation, heat, alcohol and other drugs are some of the more common stressors which may reduce a pilots "G" tolerance.

Individual physiological variations account for significant differences in "G" tolerance between individuals. The individual who is "built like a fira plug" and who has well developed skeletal musculature ganerally toleratas "G" better than the asthenic ectomorphic pilot. The magnitude of the compensatory circulatory changea ara also related to individual physiological variablas.

Tha initial effact of acceleration on the circulatory system is to reduce the cardiac output and the MAP. Thase affects are the result of pooling of blood in the capacitance vessels in the legs with consequent reduction in tha venoua raturn. After about 10 seconds the capacitance vesaela begin to fill and the venous return increases. Tha reducad MAP which is detected by the carotid bodies reflexly results in a generalized arteriolar vascoconstriction and tachycardia. The vascoconstriction helps to improve venous return and along with the tachycardia results in increased cardiac output and MAP; as a consequence, within 15 - 30 seconds there is an increase in cerebral circulation. The reflex cardiovascular response alone may increase "G" tolerance by 0.5 - 1 $+G_z$ and depending upon the level of acceleration, it may be sufficient to maintain retinal and cerebral circulation.

The most important mechanism the pilot has for increasing his "G" tolerance is a voluntary effort which consists of four specific actions:

1. Crouching - this involvas pulling his head down between his shoulders to shorten the eye to heart distance;

2. Muscle tensing - this involves isomatric contraction of the skeletal muscles of the arms and legs to prevent pooling of blood in the extremities and increase venous return;

3. Muscle tensing - this involves isometric contraction of abdominal musclature which supports the diaphragm and heart preventing an increase in the eye to heart distance; and,

4. Forcible exhalation - this involves exhalation against a partially closed glottis which increases intrathoracic pressure and pressure in the great vessels.

The forcible exhalation against a partially closed glottis is called the M-1 manoeuvre. This exhalation is assissted by the tensing of the abdominal muscles and this combined effort results in an elevation of the intrathoracic pressure which is translated directly into an increase in cerebral artery pressure and perfusion of the eyes and brain. The M-1 manoeuvre and the muscle tensing are somewhat counter productive in that the forced expiration by increasing intrathoracic pressure tends to reduce the venous return and cardiac output and lower the diaphragm and heart. Consequently, the forced expiration must be interrupted every 3 to 4 seconds to facilitate venous return. Muscle tensing can increase "G" tolerance by about 2 $+G_z$ and a properly performed M-1 manoeuvre is capable of increasing "G" tolerance by as much as 2 $+G_z$. However, as these actions are counter productive, their effects on "G" tolerance are not entirely additive.

If the onset of acceleration to 5, 6 or 7 $+G_z$ is rapid, there may be insufficient time for the compensatory cardiovascular response or voluntary action by the pilot to take effect. Consequently, blood stops flowing to the head almost instantly and the pilot will have only a few saconds of consciousness remaining. Howaver, if the onset is gradual allowing time for the reflex circulatory changes, voluntary straining and mechanical support from a "G" suit, ths fighter pilot can sustain very high "G" stress. The duration of the acceleration is important for two reasons. Under a continuous $+G_z$ acceleration stress the pooling of blood in the dependent parts eventually compromises venous return with consequent reduction in cardiac output so that decompensation may occur at a "sub-threshold" level. Secondly, acceleration stress is extremely fatiquing and a prolonged acceleration below tolerance level may result in a gradual degradation of maximum "G" tolerance.

While individual variation does account for a certain amount of the difference in "G" tolerance in individuals, the most important overall factor in the protection of the pilot against long duration acceleration is training. Included in that training, should be the understanding by the pilot that anything he gets from a "G" suit is free. Any pilot who goes flying with the specific intent or possibility of engaging in sustained high "G" manoeuvres should be wearing a "G" suit. Airplanes and lives have been lost in circumstances where a "G" suit could likely have prevented the accident and saved the life. A properly fitted and functioning "G" suit should provide the pilot with an additional 1.5 - 2 $+G_z$ of tolerance for any given

duration of acceleration.

For completeness, it should be noted that the reclined seat back, which essentially converts $+G_z$ to $+G_x$ has proven effectiveness in increasing "G" tolerance. In addition, assisted positive pressure breathing appears to have some value in increasing "G" tolerance; however, this has not yet been shown to be practical.

Tolerance to Sustained $+G_z$

From the foregoing it can be seen that if the pilot's relaxed "G" tolerance was about 4 - 4.5 $+G_z$ and he gets 2 "G" for the "G" suit, 2 "G" from the muscle tensing and 2 "G" from the M-1 manoeuvre, he should be capable of sustaining 10 $+G_z$. There are some pilots who are probably capable of withstanding 10 $+G_z$ for short periods; however, the muscle tensing and M-1 manoeuvres are extremely fatiguing and cannot be sustained for long at accelerations in excess of 4 - 4.5 $+G_z$. Furthermore, the contribution of muscle tensing and the M-1 manoeuvres are not entirely additive.

The latest generation of aircraft are capable of withstanding up to 10 "G" and of sustaining more than 7.5 "G" without loss of energy, with onset rates that make it almost instantaneous. High sustained "G" has been rather arbitrarily defined as 7 $+G_z$ for 15 seconds and it is likely that any pilot in the fighter world who cannot sustain this amount of $+G_z$ acceleration should be in some other flying environment.

Conclusion

Acceleration induced loss of consciousness and acceleration induced disorientation are serious physiological flight safety hazards to fighter pilots in the air combat environment. However, for the pilot with a properly fitted and functioning "G" suit, which is being supplied by a rapid onset "G" valve (presently in development), who has been properly trained to simultaneously carry out crouching, muscle straining and M-1 manoeuvres, the hazard is greatly reduced. The hazard is only reduced, because it is a fact that some of the new generation of aircraft simply exceed the physiological limitations of even the protected pilot and unless something is done to limit the onset rate or the maximum "G", the threat of loss of consciousness, and subsequently loss of the aircraft and the pilot, is very real.

## DISORIENTATION

Disorientation has been recognized as one of the most important problems in aviation safety since the early days of flight. In 1930, William C. Ocker, a pilot in the United States Army Air Corps, made this statement (3):

> "ONE OF THE PRINCIPLE DIFFICULTIES IN FLYING BLIND IS THAT THE PILOT EXPERIENCES CERTAIN FATIGUING STIMULI WHICH MAKE FOR HAZARDOUS FLIGHT, BECAUSE THE EFFICIENCY OF THE PERSON IS ENORMOUSLY REDUCED. THIS FATIGUE IS THE RESULT OF A NUMBER OF CAUSES AND SUBCAUSES, PRINCIPLE OF WHICH IS A PHYSICAL DISTURBANCE OF THE PILOTS NORMAL SENSE OF EQUILIBRIUM WHEN HE IS FLYING BY THE INDICATIONS OF HIS INSTRUMENTS"

This was written at a time when to fly into cloud meant almost certain destruction. Ocker went on to do some of the pioneering work in this field and actually designed the first "flight integrator", shown in Figure 15 (4). This instrument did not work because the technology had not caught up to the idea, but the instrument had tremendous potential and even in 1982, when the technology to make it work exists, a pilot could do worse than to have an instrument like this.

In the ensuing 50 years, depending upon the aircraft, much has been done to supplement the sensory system of the pilot with very sophisticated instrumentation. However, this fact is just as true today as 50 years ago; when a pilot is deprived of his visual cues for orientation; or, if he is fooled by erroneous visual information or a powerful enough vestibular illusion; depending upon the stability of the airplane and the flight conditions at the time, he will lose control of his airplane in as little as 20 seconds.

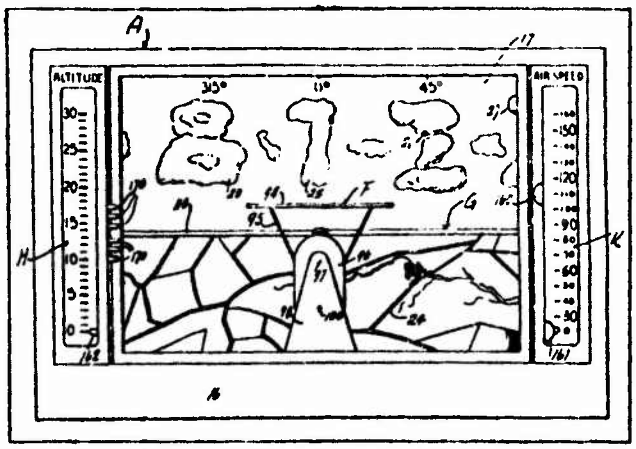

Figure 15. Flight integrator invented by Lieutenant Carl C. Crane and William C. Ocker.

Definition

Spatial disorientation is a term which is used to describe the situation where a pilot fails to perceive correctly the attitude or motion of his aircraft relative to the surface of the earth.

Disorientation may be classified into two types: in Type I the pilot is not aware that his perception of his attitude and/or motion is false; in Type II the pilot is aware of a conflict between his perception of his attitude and/or motion and his actual orientation.

In Type II disorientation, it is important to understand that there is a continuum from the smallest disturbance of comfort, when the pilot is mildly aware of a mismatch between two of his sensors, to the condition where he is in a state of complete disorientation and panic as he perceives himself to be spinning or tumbling through space in a totally disorganized fashion. The cardial characteristic of Type II disorientation is that there is a mismatch of information from two different orientational sensors.

The Type I disorientation is probably the most dangerous type of spatial disorientation. The cardinal characteristic of Type I highlights the worst aspect of spatial disorientation; that is, its insidious onset during which there is no mismatch of information between sensors. During this period the aircraft may contact the ground or enter an unrecoverable condition or attitude while the pilot is oblivious to the danger.

## Mechanisms of Orientation and Disorientation

Man has a problem with orientation in flight basically because he has adapted as a land animal and is primarily conditioned to orienting himself visually and with respect to the force of gravity. Consequently, when man's visual inputs are interfered with and the resultant acceleration vector acting on him is influenced by accelerations other than normal gravity, he has difficulty orienting himself.

The terminology for describing the direction of acceleration forces acting on body organs is shown in Figure 13.

Man has primarily three mechanisms of orientation; the kinaesthetic receptors; the vestibular apparatus; and the eyes.

The most important of the orientational sensors is vision. This can be readily seen if one tries to stand on one foot in the dark or stand with his eyes closed or even with only his peripheral vision occluded. One will find that he is quite unsteady. This exercise will also demonstrate that it is the peripheral vision which is the most powerful orienting part of the visual apparatus. It is perhaps regrettable that the main orienting instrument in an aircraft, the artificial horizon, is useable only with central vision. Because of this, a peripheral vision horizon device which casts a lazer generated gyro stablized light bar on the instrument panel, which is readily seen and interpreted by peripheral vision, is a promising development.

The obvious solution one might think is to not close his eyes or stand on one foot while flying and land before dark; however, it is not that simple. First of all, the kinaesthetic receptors and the gravity sensing part of the vestibular apparatus (the otolithic organ) are only capable of interpreting the resultant acceleration vector. When accelerations in directions other than along the normal gravity vector are introduced, these mechanisms can only confuse. Secondly, the part of the vestibular apparatus which senses rotational accelerations (the semicircular canals) is extremely limited, and is incapable of sensing correctly the rotations in three planes throughout the range that the pilot can potentially be subjected to in an aircraft. Finally, vision which is the primary orienting mechanism cannot be implicitly relied upon. This is because the pilot may be partially or totally deprived of visual cues; or, he may be fooled by some type of visual illusion. The one circumstance where vision is usually reliable is when it is focused on the instruments with a cross check which is adequate to provide sufficient orienting cues. Even then some vestibular and visual illusions may be so powerful that the pilot may disbelieve or ignore this one source of reliable orienting information. Despite this fact, the eyes are by far the least easily fooled sense organ providing information about orientation.

When visual cues outside the cockpit are being used to provide information about orientation, there is a direct interpretation of attitude and motion relative to the earth which is not readily misinterpreted unless the visual information is degraded by cloud, lighting conditions or physiological factors. When vision is concentrated on the cockpit cues provided by the instruments, the necessary information is almost invariably available and correct; however, there is now an additional step in the perception process in that this information must be interpreted. When the pilot looks at an instrument he does not see the real thing; he sees a representation of the real thing. This representation lacks the input strength of the real visual information which he sees when he looks out of the cockpit; therefore, if his attention is distracted by something like an emergency warning light or an erroneous vestibular sensation, the signal from the instrument may not be sufficiently strong to provide adequate orientational cues for him to act upon.

The pilot is also provided information about his attitude and motion by the vestibular apparatus. Unfortunately, the vestibular apparatus provides correct information only under conditions of earth normal gravity and within a very limited range of accelerations in other planes. The vestibular apparatus has two functional parts which provide orientational cues: the utricle, which contains the otolithic organs, and the semicircular canals.

The otolithic organ is a beautifully simple little apparatus for determining the orientation of the head relative to the force of gravity, providing that the only acceleration that the head is being subjected to is that of gravity (Figure 16). The most simplistic picture of the otolithic organ is to think of it as a weight on top of a flexible pole. When the pole is aligned with the force of gravity, the force of the weight is transmitted directly along the axis of the pole, creating no moment force. The resultant activity in the nerve cells is interpreted as the head being aligned with the force of gravity. When the head is out of alignment with normal gravity, a moment force is created which stimulates nerve cells at the base of the pole. The direction of the resultant force is assessed by the brain to determine correctly the direction of head tilt. When a linear acceleration or decceleration of 0.5 Gx produces a resultant force which is no longer aligned with the normal gravity vector, the otolithic organ

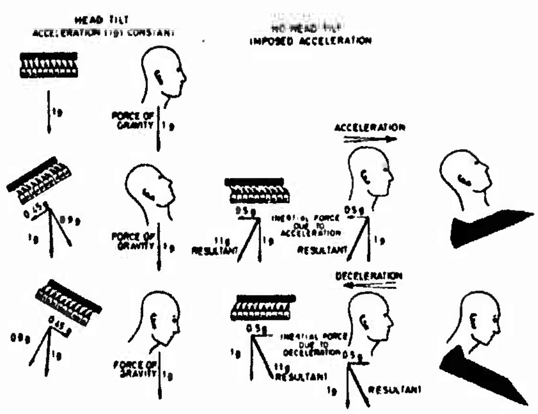


Figure 16. On the left, the otolith correctly perceives head tilt in a normal gravity environment; on the right the otolith incorrectly perceives pitch attitude when exposed to a small linear acceleration. Modified from Aviation Medicine (10).

assumas that the rasultant force is aligned with the normal gravity vector and the perception of the attituda of the aircraft undar this additional acceleration or decceleration is that the aircraft is climbing or descending (Figure 16, right). This is callad the somatogravic illusion and it occurs most frequently on take-off or overshoot, where the linear Gx accelerations in modern jet aircraft can be quite significant. If the pilot reacts to this illusion the consequences can be extremely grave, because the natural reaction of the pilot to this illusion is to check forward on the stick which may place the aircraft in a descent at very low altitude. Under certain circumstances this illusion can be overpowering. There have been a number of major accidents both in military and civil aviation where, in reacting to this illusion, the pilot flew into the ground shortly after take off. The term "jet upset phenomenon," has been used by some to describe the somatogravic illusion in its most extreme form. The real and the illusory attitude and flight path of an aircraft involved in a major airline accident in which this illusion was the cause factor are illustrated in Figure 17.

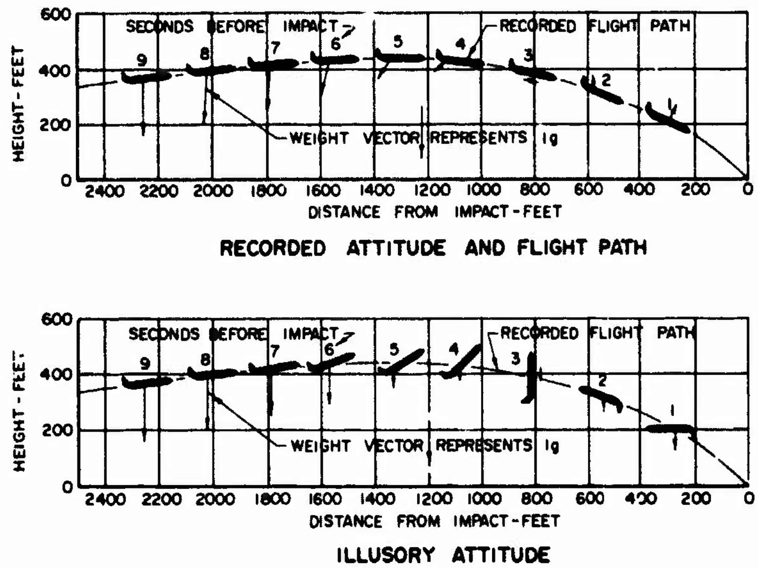


Figure 17. (Top) The racorded attitude and flight path of the aircraft during the final 10 seconds of flight. (Bottom) A representation of what is believed to be the attitude of the aircraft as perceived by the pilot suffering from an extreme somatogravic illusion.

Three interconnected semicircular canals are designed to sense rotary accelerations in the yaw, pitch and roll planes. While the "pitch" and "roll" canals are not perfectly aligned with the pitch and roll axes, the brain is capable of correctly interpreting rotations in these planes within the range of sensitivity of the organ. Contained within an expansion of each semicircular canal there is a gelatinous structure which is analogous to a baffle which is called the cupula (Figure 18). At the base of the cupula, there are embedded sensory cells which communicate with the brain. The activity of the sensory cells is determined by the deflection of the baffle or galatinous membrane which is subjected to the force of the fluid within the canal as it is accelerated by some rotation of the head and/or body. These canals are stimulated by angular accelarations as low as $0.05^{o}$/sec/sec; however, accelerations of much greater magnitude than this can go undetected if the pilot is pre-occuppied. The weakness of this system, is that it is only designed to detect accalerations and if the rotary acceleration is followed by constant velocity rotation, the perception of rotation disappaars (Figure 19). There is an initial perception of rotation as right

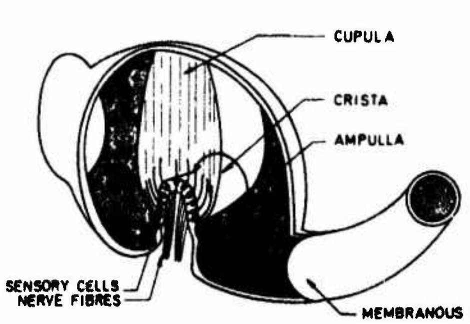


Figura 18. A schematic illustration of the expansion of aach semicircular canal which is called the ampulla. Contained within the ampulla is a "baffle-like" mechanism, the cupula, which reacts to the inertia of the fluid contained within tha canal.

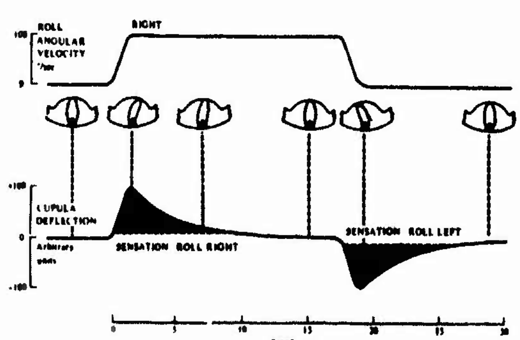


Figure 19. (Top) The deflection of the cupula during the "roll-in," "constant rate roll" and "roll-out" of a prolonged rolling manoeuvre. (Bottom) The perception of roll as indicated by the vestibular sensations.

aileron is applied; however, once tha desired rate of roll is achieved, the rotational velocity becomes constant and within about 10 - 15 seconds the sensation of rolling stops. Consequently, the vestibular sensation in a coordinated roll may be one of being straight and level. If then the pilot stops the rolling on recovery to wings level by centralizing the ailerons, the resulting decceleration is perceived by the pilot to be a roll in the opposite direction, rather than a recovery to wings level which is what the instruments should now show. There now exists a potential for sensory conflict; the instruments through the visual sense register straight and level, the vestibular apparatus registers a bank or roll to the left. To correct for this, the pilot leans to the right in order to "erect" his vestibular apparatus; hence, he is said to be suffering from the "leans."

Another mechanism for inducing the "leans" is shown in Figure 20. If the roll into a turn occurs at a subthreshold rate because of an inadequate instrument crosscheck; or if the roll occurs above threshold while the pilot is distracted, and then the pilot observes the previously undetected bank, a conflict between the visual and vestibular sensors exists. If the pilot then levels the wings at an above threshold rata, the vestibular interpretation will be one of banking in the opposite direction while the visual input will be one of wings lavel. The sensory conflict will continue to exist and the pilot will lean in the direction requirad to "level" his horizontal semicircular canal.

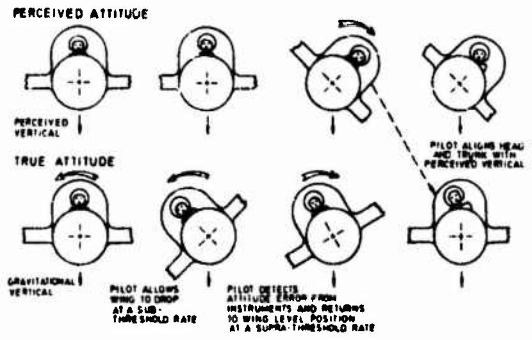


Figure 20. This illustrates the classical development of the "leans."

This illusion can be overpowering and, once the conflict occurs, the longer it exists the more powerful it becomes. The illusion occurs in perhaps its most severe form in formation where a wingman is using his lead as his primary visual reference. In flight conditions where the horizon is not readily visible in his peripheral field, there is an inclination for the wingman to interpret the lead's wings as a horizontal reference, whether they are horizontal or not. As long as there is no conflict there is no problem. A conflict is likely to occur, however, when the lead rolls; the wingman perceives a roll with his vestibular apparatus but his only visual reference (the lead) is not seen to change. The lead is still visually interpreted as level but the vestibular apparatus has sensed the roll. Under these conditions the wingman can easily become severely disoriented and interpret that the formation is steeply banked or inverted. This conflict can seriously degrade his performance to the extent that he may lose the lead or intentionally break-off. When this occurs he haa lost his only contact with orientation (the lead) until such time as he can orient himself on his own instruments. Unfortunately, the wingman will require a minimum of 20 seconds (longer depending on his degree of disorientation) to orient himself. Twenty seconds may be an eternity in the life of a lost wingman who may contact the ground or enter an unrecoverable condition of flight or attitude before he can assume responsibility for his own orientation. All of the vestibular illusions are much more likely to occur in formation as the wingman is using a visual horizon reference (the lead) which is "not reliable."

The third source of orientation information comes from the kinaesthetic receptors; the sensory endings in the skin, joints, ligaments and deepar supporting structures which are usually referred to as the "seat of the pants" sensation. In general these receptors sense touch and pressure and in the normal gravity environment, the direction of gravity. Once the aircraft becomes airborne and can be subjected to accelerations in any plane the ability of thasa sensors to detect earth-vertical is seriously impaired. What these receptors do provide the pilot with, is extremely important information about the position of his head relative to his body and about the position of hia body with respect to the aircraft with which he is in immediate contact. When the pilots vestibular apparatus gives him information about the orientation of his head, he has two ways of interpreting the orientation of the aircraft; either visually, or with these proprioceptors which tell him where the airplane is relative to his head. It follows logically that if he correctly senses the orientation of his head, he knows the orientation of the airplane.

There ara a multitude of other vestibular and visual illusions which can contribute to disorientation which cannot be dealt with here and the reader is referred to a textbook of aviation medicine for further study.

Conclusion

Disorientation occurs in one degree or another to all pilots. Fortunately, in most cases it is only an aggravation, but frequently it is an aggravation which distracts the pilot from his primary task and degrades his performance. More than occasionally, it is a contributing or primary cause factor in an aircraft accident. The disorientation accident is usually a bad accident. In some cases, the pilot may eject and be available to the accident investigator, but all to often the disorientation accident ends up in a smokey hole with very little remaining to piece together the cause of the accident. The number of accidents where disorientation can be clearly identified as the cause factor are unfortunataly few because of the severity of the accidents. Consequently, the reported incidence of disorientation accidents is perhaps lower than it actually is. On the other hand, disorientation is high on the list of the possible cause factors in "cause undetermined" accidents, and in this type of accident its incidence as a possible cause is perhaps inflatad. Statistics indicata that in the single or two place military combat training aircraft, disorientation accounts for between 5 and 10 percent of all major accidents and a disproportionately high loss of the aircraft and pilot. The incidence is less in the transport environment because of the multicrew situation and the minimal manoeuvring that is carried out. Disorientation is a major concern in rotary wing aircraft where the dimensions for movement are greater, the instrumentation to interpret the movement is non-existant or marginal, and operations are conducted largely in a environment where the margin for error is small.

The keys to preventing the disorientation accident are:

1. A human engineered cockpit designed to provide the pilot with the most graphic and reliable orientational information that leaves minimal room for misinterpretation;

2. Aeromedical training which provides the pilot with a basis for understanding disorientation and recognizing his own limitations; and

3. In flight familiarization with disorientation accompanied by hands on practice of aircraft control and handling during vestibular illusory stimuli.

## VISION IN AVIATION

Of the five senses, vision is undoubtedly the most important in the flight environment. Vision in aviation involves two specific processes; first there is the "seeing part" and secondly there is the "perceiving part."

Seeing, involves looking in the right place; detecting that something is there (an indistinct object, movement or reflection); focusing on the object; and, identifying the object. At about the point where identification of the object begins, the "seeing" or objective part of vision blends imperceptibly into the subjective aspect of vision. Perception begins with identification or recognition - "It's an aeroplane. What type of aeroplane? Is it hostile?" In the visual process there follows a phase where a number of judgements must be made; "Is is coming or is it going? Is it high or is it low? Is it crossing in front or behind, or maintaining a constant angle off? Should I break high, break low, break right, break left or do nothing?"

The part of vision which involves looking in the right place, and identifying and recognizing objects is a learned process; the parts of vision which involve detection and focusing the object are physiological processes: the part of vision which involves use of that visual information which is seen, to make judgements and take action is an information processing activity. The information processing activity involves a mixing of raw visual information with experiences stored in memory and is a largely subjective mental process, which under certain circumstances can grossly misinterpret what may seem to be graphic raw visual information.

For many aircrew who suffer a degree of paranoia about their medical categories, the "seeing part" of vision is frequently the focus of this paranoia. However, as important as it is, vision is an infrequent cause of jeopardy to a pilot's medical category. This largely is a result of selection standards but it is also because it is believed that within certain limits the perception or learned part of vision should improve with age and experience and offset any degradation of the physiological part which inevitably occurs with increasing age.

### Seeing

The physiological part of the eye functions much like a simple camera. To get a clear picture, like a camera, the most important factors are the lens, the film and the lighting conditions. The primary determinant of how well a pilot sees, providing there is adequate lighting, is the ability of the lens to focus the image clearly on his retina (Figure 21A). The ability of the lens to focus an image on the retina by changing its shape, so that it increasingly refracts light as objects come nearer, is called accommodation (Figure 21B). There are primarily two types of refractive errors of concern in aviation; hypermetropia or "long sightedness," and myopia or "short sightedness."

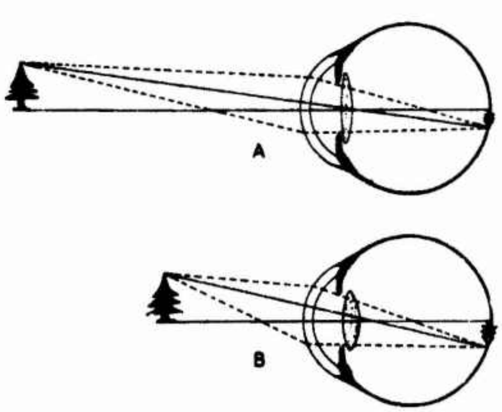


Figure 21. In the normal eye with accommodation relaxed the image of a distant object is focused clearly on the retina (A). When the object is moved closer to the lens, the shape of the lens changes (accommodates) so that the image remains focused on the retina (B).

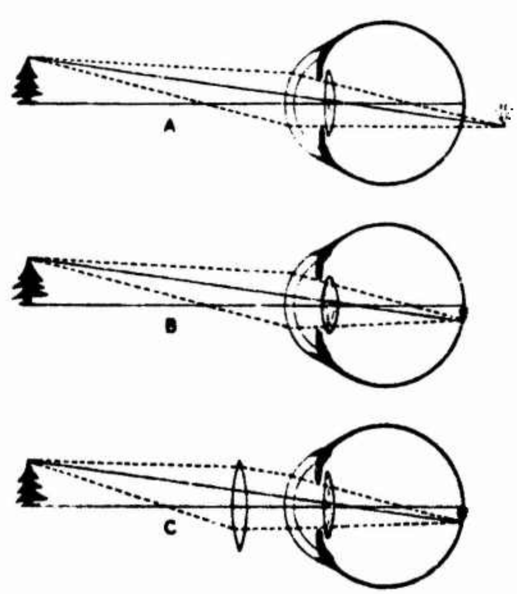


Figure 22. In hypermetropia the image of the near object is formed behind the retina and is blurred (A). A convex lens must be added to effectively increase refraction so that the image is focused on the retina.

Hypermetropia is the commonest refractive error. Manifest hypermetropia exists when the refrective mechanism of the eye does not have the cepacity to refract light sufficiently to focus neer objects on the retina; consequently, tha image is formed behind the retina, snd is therefore blurred (Figure 22A). As can be seen from Figure 21B, the nearer the object is, the more accommodation is required to focus on the retina. In youth, the eye has as much as 12-16 dioptres of eccommodative power; however, this decreases relatively predictably, so that by 40 - 50 years of age there is only about 4-5 diopters of accommodative power remaining (Figure 23). Hypermetropia involves no impairment of distant vision. The difficulty for the pilot in

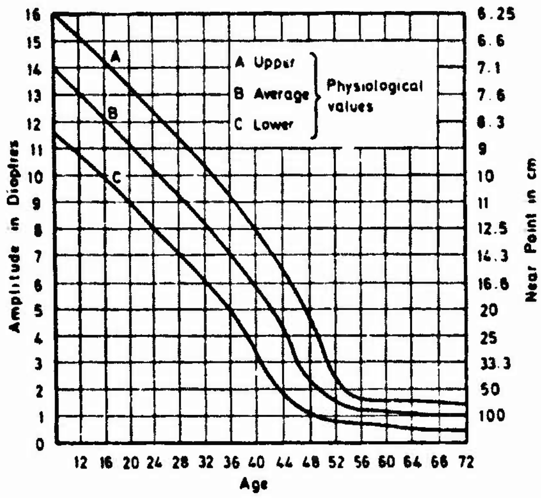


Figure 23. Illustrates the decrease of accommodative power of the lens with age.

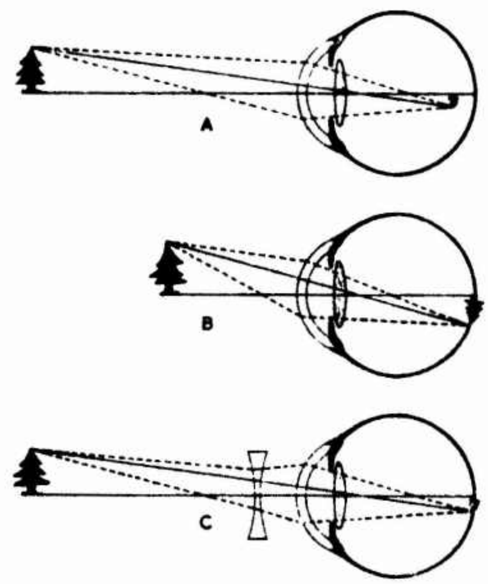


Figure 24. In myopia the image of e distant object is formed in front of the retina and is therefore blurred. In order to focus the image clearly on the retine e concave lens, which effectively decreeses the amount of refraction, must be used.

the cockpit is the range of short focal lengths that he must cope with. Some pilots will have difficulty focusing neer objects in the cockpit beginning eround the age of 40. To correct for hypermetropia the refractive power of the eye must be increased by providing a convex lens (Figure 22C).

Myopia exists when the visual apparatus has such fixed refractive power that the image is focused in front of the retina and is therefore blurred (Figure 24A). Accommodation cannot correct this error because accommodation brings the image "forward," which would only aggravate this problem. Myopia can usually be corrected with a conceve lens which spreads the light rays (Figure 24C). Myopie is etrongly hareditary and is usually manifested during the growth years. Most myopic people cannot pass the standerd visual acuity tests and the myopic is not usuelly seen in avietion.

If a pilot must be issued with glasses, either for the first time or due to a change in his refractive error, it is importent that he have a flight check with e quelified pilot before being authorized unrestricted flying. This is because of the importance of the pilot's memory for what the approech and landing picture looks like; this is significantly altered by a refrective lens. A refrective lens, in making objects clearer may make them look larger or smaller depending on whether it is a positive or negative correction. The effect of this on the pilot's depth perception end his memory picture of the lending environment is obvious. These small alteretions of depth perception are probably most critical during the flare and lending in a helicopter, but apply equally in any aircraft operation requiring precise depth perception.

There are a multiplicity of other factors which influence the pilots ability to see other aeroplanes. Quite apart from whether the pilot has the ability to focus, is the fect that in order to focus he has to see something. When a pilot hes an empty visual field or when he knows that "something is out there" and he is looking into an empty sky to try to find another aeroplane, the reaction of the eye is to accommodate. When the eye accommodates, the focal point is brought closer to the eye. Consequently, when the pilot strains to see something, unlees he does something to prevent it, his eyes will progressively accommodate until they are focused at about 6 to 20 feet. It is obvious that with his eyes focused at 6 to 20 feet, a pilot will not see anything that is one half or one mile away unless it is very big. Since most aeroplanes are really a point source of light and may be considered to be at infinity beyond about one half mile, this is a significant problem.

A pilot with 6/6 vision only has this vision when he is looking directly at an object. If he is looking for a point source, not only must his focal length be right (accommodation completely relaxed), but the image must fall on the most sensitive part of the retina, the fovea, where the highest concentration of cones are (Figure 25). It is evident from this illustration that if the object is as little as 20° off the central vision point the visual acuity is only 1/10 of central vision. What this means in real terms, is that if the object is as little as 20° off central vision it potentially reduces the detection distance

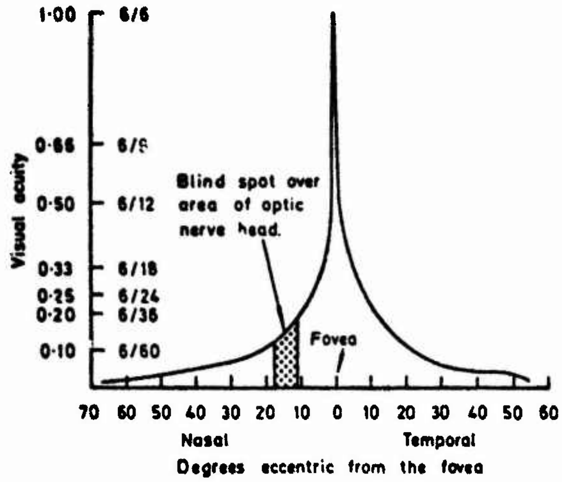


Figure 25. Illustrates the decrease of visual acuity for objects which are eccentric to the point of maximum central vision, the fovea.

| | Detection Distance* |
|---|---|
| Centrel Vision | 4.5 Miles |
| Peripheral vision (20$^{o}$ from the centre of field of vision) | 0.45 Milee |

*Fuselage size of 7 feet diameter

Figure 26. Illustrates the reduction in detection distance for an object in the peripheral vision due to the marked reduction in visual acuity of off-central vision.

by a factor of 10 (Figure 26). Therefore, in the daytime, in order to see another aircraft soonest, the pilot has to be looking directly at it.

It is a big sky and if the pilot does not have information about where to look (from redar, radios, etc.,) he has to "seek and find." An organized visual search pattern is likely to be more productive than a random pattern. The eye sees very poorly when it is moving so that the organized visual search process must consist of a continuous process of "scan, stop, focus"; "scan, stop, focus."

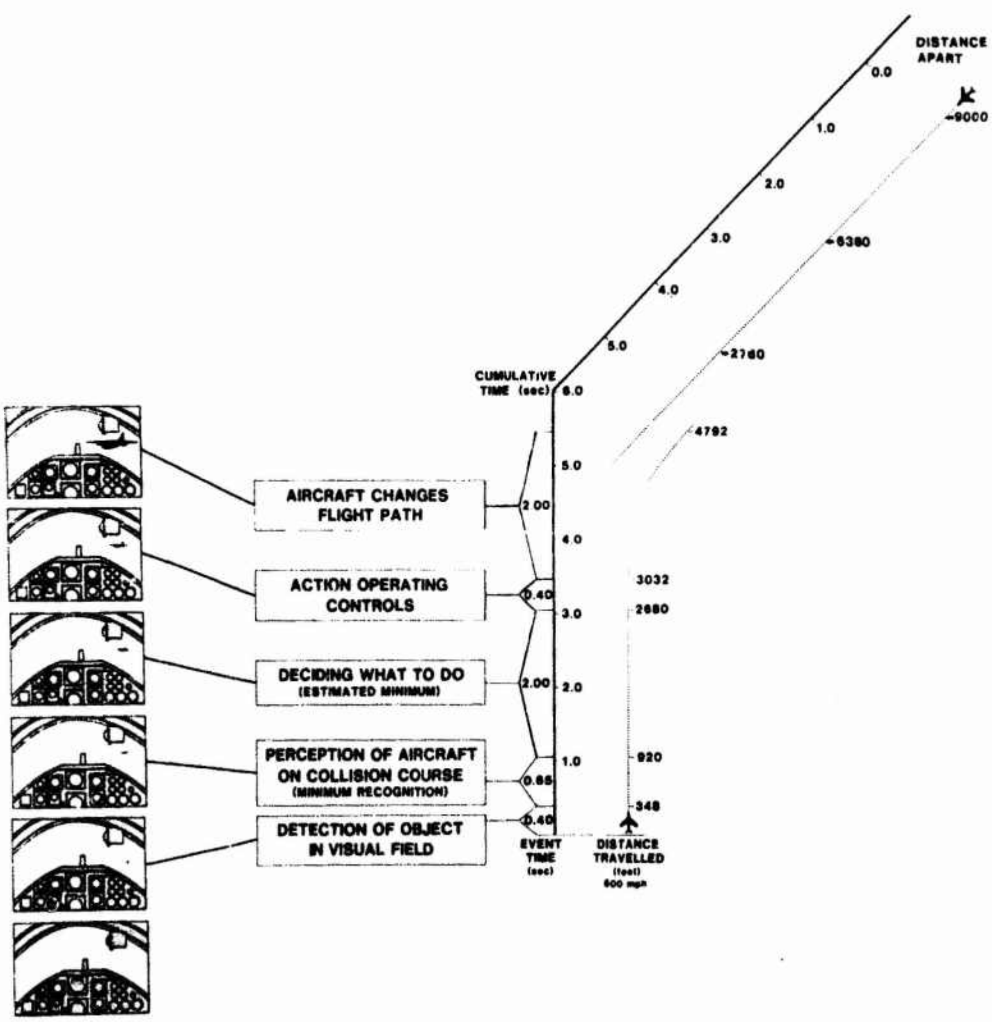


Figure 27. The time course of "seeing," "perceiving" and reacting for the pilots of two aircraft on a collision course. On the left, what the pilot "sees" during the last 6 seconds before potential collision.

At night the visual search process is similar but now the visual acuity of the retina is reversed; the cone cells involved in central vision are much less sensitive to low levels of light than the rod cells involved in peripheral vision. This means that dim objects are more likely to be seen if they are just off centre. The rapid fall in visual acuity of off-central vision shown in Figure 25 somewhat offsets this, so that the object has to be so close before it is seen that this technique really is not useful for seeing other aeroplanes, except in formation. The technique is of value in the unlit landing environment which may be encountered by helicopter pilots. If there is any lighting at all, the pilot must revert back to central vision because it is the most sensitive and because the light will have neutralized his night vision.

Figure 27 illustrates the time and distance involved in the process of "seeing" and reacting to what is seen in a realistic flight situation. While this illustration has a degree of laboratory artificiality it can be seen how two aircraft with a combined closing speed of 1200 mph, on a perfect collision course inside of two miles, may have a mid-air collision before either pilot can do anything about it, even though they "see" each other.

Perceiving

Once the pilot is able to see the object he is only part way there. He must then go through the process of recognition, making a decision about what he is going to do and then reacting to that decision.

There are many situations in aviation where the problem is not in seeing but in the interpretation of what is seen. This particularly is true in the landing environment and it would be quite safe to say that a very high percentage of approach and landing accidents and incidents are related to a misinterpretation of visual information rather than a lack of visual information. There is an axiom that, "it is the vestibular illusions which get the pilot on take-off and overshoot, but it is the visual illusions which get him on landing."

The brain has to interpret visual stimuli and put a meaning to them before they are perceived, and any inadequacy of the stimulus can lead to a faulty perception. The pilot does not perceive the world just as a camera records it. He gets a dynamic moving picture which is influenced by highly personalized views and past experience. Consequently, his brain manipulates the raw data to create a picture which he thinks he understands. Unfortunately, what he then "perceives" may be what he expects to see or what he wants to see rather than what is actually there.

One of the most powerful influences of what the pilot sees, is what his brain expects to see. The brain depends on past experience and memory to develop a complete and meaningful picture. For most situations with a given set of visual cues there will be a corresponding visual understanding of that situation imprinted in the memory. Consequently, at a future time when a similar set of visual cues are present, the brain has an expectation of what the complete picture is, and even though the visual meaning may be different the pilot interprets the visual cues based on what is in his memory. Probably the most graphic example of this process in operation is the pilot who, on a bad weather approach, breaks out "at limits" perfectly lined up with a parallel taxiway. What the pilot wants desperately and expects to see when he breaks cloud on a bad weather approach is that he is perfectly lined up with a wide, long and well lit runway. That is exactly what he may "perceive," notwithstanding the fact that what is actually there is a 100 foot wide taxiway with blue lighting which has a bend in it about 4,000 feet down. This is more likely to occur if the pilot is time stressed (he only gets a glimpse of the picture); or, if he is physiologically stressed by fatique, drugs, alcohol or illness. Under these circumstances it is more likely that his expectancy will override the true interpretation of the raw data. This kind of visual misinterpretation is also more likely to occur when the information that the pilot is getting is a representation of the situation from his instruments, which in turn has to be interpreted by his brain to develop a picture of what the real visual meaning is.

One of the most important judgements that a pilot must make during the approach and landing is to estimate his height above ground. How he does this is not completely understood and probably varies from individual to individual but it appears to involve a complex integration of continuously changing raw visual information with past experience. The raw information comes from both outside and inside the cockpit. Using outside visual cues, judgements of distance, speed and glide slope angles are influenced by fairly objective central vision cues. However, they are also strongly influenced by a "global picture" that is developed by complex subjective estimations of altitude and distance based on rates of change of angles, relative sizes of objects, and texture. Using this kind of information the pilot places his aircraft in such a position that all of these factors "look right." If one or other of the factors is disturbed, the pilot will be inclined to manoeuvre the aircraft so that the picture again "looks right" and sometimes this can be a fatal mistake.

It is is impossible to deal with all the factors that can be involved here but it is worthwhile looking at some. The reader is cautioned about trying to typecast any specific incident or accident based on these factors, which flight surgeons have on occasion had an inclination to do. It is not possible to do this because these situations are so dynamic and because sufficient correct information is almost always there. In analyzing any accident or incident, the most that can be done is to determine what factors may have been present which may have led the pilot to misinterpret existing visual data.

For a very long time many thought that the ability of the pilot to judge distance and depth was due to stereopsis. Most now recognize that the retinal disparity resulting from differences in the retinal image does not contribute a great deal to depth perception except at very close range and very low altitude when the pilot is looking directly at the ground near the touchdown point, as in the flare and landing of a helicopter.

The judgement of both distance and height is thought to be influenced significantly by the size of the retinal image. The size of the retinal image is directly proportional to the size of the object in the visual field and inversely proportional to its distance. When the pilot views an object at a distance, he assumes that it is a standard size based on past experience with the object, and the size of the retinal

image is therefore a measure of its distance whether it is the slant range or vertical height above ground. This is referred to as size constancy and constitutes a strong cue to the judgement of distance and height. This is the factor that is operative when one observes a jumbo jet on takeoff or landing and it appears to be moving very slowly. Because the aircraft is so large the brain interprets it as being near. If an aircraft is nearer it should cross the visual field faster. In the case of the jumbo jet it only appears to be near and therefore it is interpreted to be moving slower. This factor can also play a part in a pilot's misjudgement when approaching a runway of different length and/or width than that which he is accustomed to; or, when approaching over terrain where the texture of the approach path is influenced by the size of the vegetation growing thereon. Fine texture suggests height and course texture suggests nearness to the ground.

Motion parallax refers to the movement of objects in the visual field. The apparent movement of objects in the visual field during approach is influenced by height and speed and to a certain extent the slope of the land on which the objects lie. If an aircraft is approaching at constant speed at a fixed glide angle the touchdown point should remain stationary and all other objects in the field should be expanding at different velocities according to a pattern similar to that shown in Figure 28. As with other

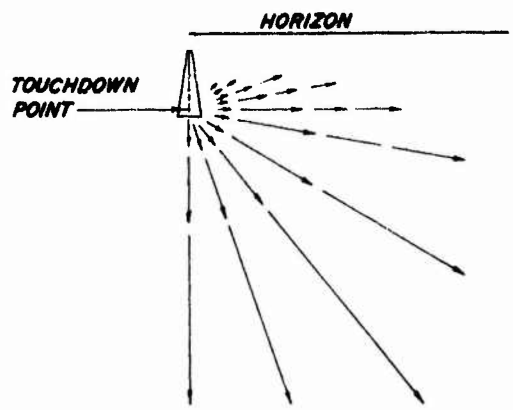


Figure 28. The relative movement of objects in the pilot's peripheral field as he approaches the runway.

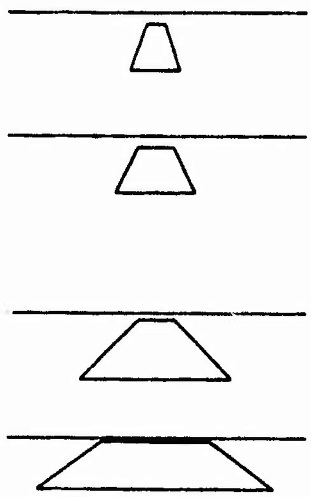

Figure 29. From the top, the pilot's perspective of a level runway at 2 miles, 1 mile, ½ mile and over the approach lights. The free horizontal line represents the horizon.

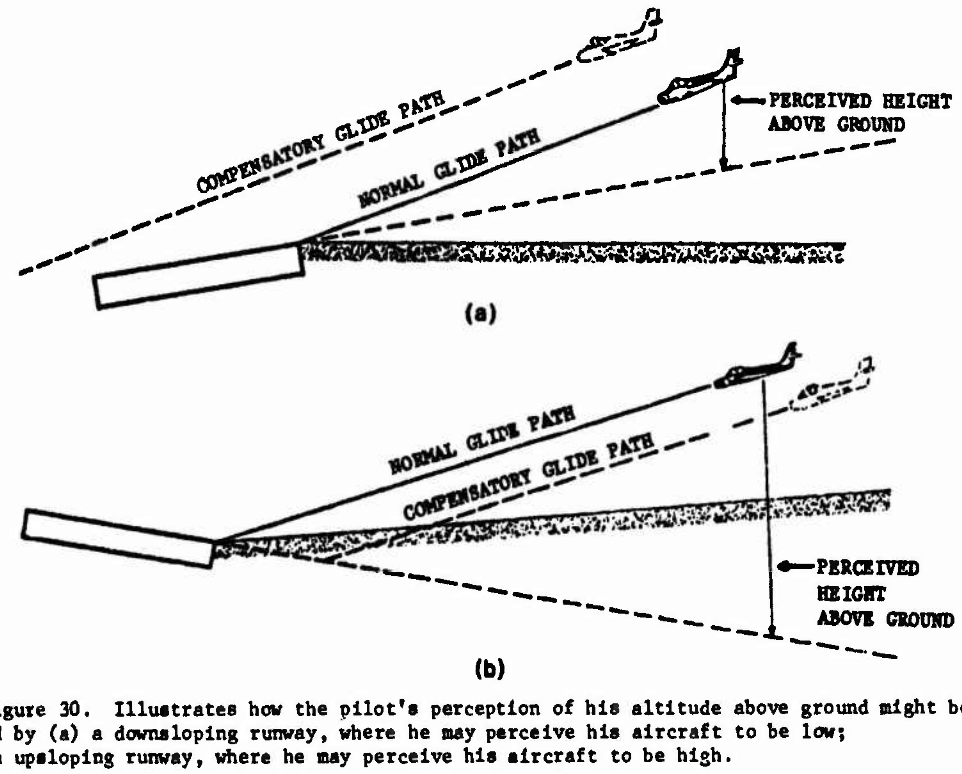


Figure 30. Illustrates how the pilot's perception of his altitude above ground might be influenced by (a) a downsloping runway, where he may perceive his aircraft to be low; and (b) an upsloping runway, where he may perceive his aircraft to be high.

visual information available during approach and landing, the pattern of movement of objects in the visual field will be learned by the pilot and become part of the "global picture" that he develops and attempts to place himself in for a given distance, approach speed and glide angle. This cue to the judgement of height and distance is probably most important at night using ground lights inside of 2 - 3 miles when other visual cues are minimal or absent.

Using linear perspective, the pilot combines judgements of size, shape and slant in developing his "global picture" of the approach and landing environment. Judgements about this extremely complicated stimulus are strongly influenced by experience and miscalculations might be expected during approach and landing to runways where the slant/size/shape relationships are non-standard or just appear non-standard as may be the case with a sloping runway. Figure 29 illustrates the pilots linear perspective of a level runway at 2 miles, 1 mile, ½ mile and over the approach lights. If this is what the "right" picture look like, changing the slope of the runway or even just a part of it from level to 3° up or down will significantly change the picture at any selected position along the approach path within 2 - 3 miles of touchdown. If the runway is sloping up the approach angle will appear steeper and the pilot will "feel" high and if he compensates by reducing power or altitude he may undershoot (Figure 30 b); if the runway slopes away the converse is true and he may land long and have difficulty stopping (Figure 30 a).

It must always be remembered that there may be multiple illusory cues mixed with valid ones, and that the total effect on the pilot's perception of the approach and landing environment is unpredictable. If he is unstressed, he should be able to deal with these illusions; however, if he is approaching in bad weather, or at night or fatigued or pre-occupied by some cockpit emergency, he may allow himself to be dangerously misled.

The key to the prevention of the landing accident due to a visual illusion is training. The more keenly the pilot is aware of his limitations and the situations where he is likely to be fooled, the more preparation he can make to avoid them using all available cues including altitude and distance information from his instruments and other approach aids such as VASIS and Radar.

## ACUTE CAUSES FOR GROUNDING AND SUDDEN INCAPACITATION IN AIRCREW

For the purpose of this presentation, sudden incapacitation will be defined as partial or complete impairment of performance of a crew member by physiological or psychological factors occurring in flight. Complete incapacitation usually implies loss of consciousness, although loss of consciousness is not necessary. A pilot suffering from intense pain or disabling anxiety, for instance, may be effectively completely incapacitated. Mention of some of the acute causes for grounding is appropriately included in this presentation since one of the primary reasons for grounding an airman is to prevent incapacitation in flight. The acute causes for grounding are considered to be either those temporary or permanent physiological or psychological conditions which would present a hazard to safe flight through degraded performance by partial or complete incapacitation. The judicious and conscientious grounding of aircrew for cause is one of the primary accident prevention tools of the flight surgeon.

By far the commonest acute causes for gounding are very minor and transient illnesses which involve roughly in descending order of magnitude; the upper respiratory tract; the upper gastroinestinal tract; the lower gastrointestinal tract; the musclo-skeletal disorders; and, the urinary tract. The triviality and transience of many of these conditions belies their importance and one might take the position that the minor sniffles and sore throats, diarrheas and nauseas and assorted aches and pains should not occupy the flight surgeon's concern. From the point of view of demand on his clinical acumen, they should not; however, there are two extremely important reasons for paying considerable attention to these problems. First of all, they present an ideal opportunity for the flight surgeon to communicate preventive medicine and associated flight safety principles to the pilot. It is during these contacts that the aircrew should come to understand the role of the flight surgeon in support of flight operations and hopefully gain confidence in the flight surgeon's ability to deal with their medical problems. The relationship developed at this point will pay dividends when a serious medical problem presents to the airman; when he will then be more likely to bring the problem to the attention of the flight surgeon. Secondly, not only are these minor illnesses the commonest cause of grounding, but untreated or managed improperly, they are probably the commonest cause of partial incapacitation in flight. It is the flight surgeon's ability to intervene at this point to prevent the pilot from flying with a minor illness which may be partially incapacitating, in a way which protects both the interests of the pilot and the organization, which will enable him to prevent the pilot from flying with more serious conditions which may be totally incapacitating and catastrophic.

Figure 34 lists most of the major causes of sudden incapacitation in flight under five separate categories. The list is not exhaustive but includes all except the rarest and most unpredictable causes of incapacitation. An attempt has been made to present the causes of incapacitation sub-classified in categories in descending order of magnitude of concern from left to right and within each category in descending order of magnitude of concern down the column. It is recognized that this method of classification would be difficult to completely substantiate; however, it is useful to examine the cause with some degree of perspective on their likely incidence and severity. It is evident that the four right hand columns are essentially the same as a list of the acute causes for both temporary and permanent grounding.

This brief discussion will be limited to only a few of those physiological and psychological conditions which are considered to be of greatest concern as causes of incapacitation, and which may manifest independent of flight stresses. It is important to remember that any of these conditions are likely to be aggravated by in-flight stress. In limiting the discussion, there is an immediate problem of defining concern; is it greatest for the most incapacitating, yet extremely rare cause, or the less incapacitating but more common cause?

As stated previously, complete incapacitation may or may not involve total loss of consciousness (LOC). When it does, it is often catastrophic and unfortunately it is not uncommon. Rayman (5) reviewed USAF experience with LOC between 1966 and 1971 and found 32 documented cases of which 7 were fatal. A similar result was probably prevented in 23 other instances by the presence of a second pilot; and, in only 2 cases

| Flight Stresses | Minor Illnesses | Psychiatric Factors | Drugs | Major Illnesses |
|---|---|---|---|---|
| Disorientation<br>Acceleration<br>Hypoxia<br>Fumes in the cockpit<br>Decompression sickness<br>Airsickness<br>Pressure breathing<br>Syncope | URI with otitic or sinus barotrauma<br>Gastrointestinal upsets<br>Food poisoning<br>Musculo-skeletal - cramps | Neuroses - Disabling anxiety<br>Alcoholism<br>Suicide<br>V/V syncope | Alcohol<br>Prescribed drugs<br>Self medication<br>Illicit drugs | Cardiac - ischemia - arrhythmia<br>Renal - atone<br>Gastrointestinal - upper GI bleed - visceral pain<br>Respiratory - acthma - spontaneous pbaumothorax<br>Acute surgical conditions - appendicitis<br>Neurological - intracerebral/event - migraine - seizure disorder |
| *HYPERVENTILATION | *HYPERVENTILATION | *HYPERVENTILATION | *HYPERVENTILATION | *HYPERVENTILATION |

Figure 31. A limited list of potential causes of sudden incapacitation in flight.

when the pilot was alone did he survive. Rayman (6) has again recently reviewed USAF statistics on incapacitation for the period 1970 - 1980; of 146 incidents, 28 involved loss of consciousness, of which none were fatal. In 23 of these cases, a second pilot regained consciousness in time to safely recover the aircraft.

It is quite possible that these figures underestimate the problem. By its nature, this cause factor is difficult if not impossible to prove in fatal accidents. Secondly, cases of partial incapacitation which do not result in an accident are likely very significantly underreported by aircrew for fear of consequences. Finally, in some instances, with complete incapacitation, for example following acceleration stress, the pilot may not even be aware of the episode.

With distracting from the importance of complete incapacitation, it is a fact that most of the incapacitations in the air that come to the attention of the flight surgeon are partial incapacitations. This is perhaps because those which result in complete incapacitation, unless they occur in the multicrew cockpits, are very likely to result in loss of the aircraft and pilot and anything that can be determined about the accident usually will be speculative. This is somewhat supported by Rayman's (4) earlier study of LOC where he found that only 9 of the 32 documented cases occured in single place aircraft. This is perhaps a disproportionately small number. In another study by Rayman (7) over a 5½ year period, the USAF documented 89 cases of sudden incapacitation of which 53 did not involve LOC. In Rayman's (6) most recent study, which slightly overlaps the previous studies, in the 11 year period 1970 - 1980, of 146 incidents of incapacitation, 4 out of every 5 of them were only partial incapacitations.

Since cardiac events are the most frequent cause of sudden incapacitation of men in the general population, they might be expected to be the commonest cause of incapacitation in military aviation. Interestingly, cardiac causes of sudden incapacitation in flight are relatively unusual. Mohler (8) reviewed fatal general aviation accidents due to cardiovascular incapacitation in the US in 1974 - 75 and found only 13 cases. Considering the number of general aviation movements in the US during this period, this must be considred rare. These accidents did, however, account for about one percent of fatalilities in general aviation accidents. In 1979, there were only 8 documented cases of sudden incapacitation attributable to cardiac causes reported in the whole of civil air transport worldwide; none of these resulted in an accident. This also is a small number considered the amount of aviation that this encompasses, in a population which is older and may not be as highly selected or as fit as the military aviation population.

In military aviation, a review of USAF statistics by Rayman (9) for the 10 year period 1962 - 1971 found only two documented incidents where in-flight myocardial infarction was confirmed and in both incidents the aircraft landed safely. Over the same period there were five other fatal accidents where myocardial infarction was highly suspect. In his more recent review of an eleven year period in the USAF, Rayman (6) reports 5 cases of suspected myocardial infarction of which only one was fatal. Over approximately the same period the Canadian Forces has had no accident attributed to coronary events and has had only two fatal accidents where complete incapacitation due to a coronary event was suspect. Even though potentially incapacitating coronary artery disease is an alarmingly frequent finding in even the youngest of our aircrew involved in fatal accidents, attesting to its prevalence in our population, it is usually an incidental finding. Most coronary events in aircrew occur on the ground which is probably related just to the fact that most aircrew spend less than 1/24th of their time in the air. From a very simplistic statistical point of view therefore, only one in every 24 coronary events should occur in the air. This factor obviously applies to any incapacitation: the probability of a rare event occuring in the air in a very healthy, highly selected youthful population is only 1/24th that of it occuring in the same population on the ground; hence, it is a very unlikely event. Considering also the fact that it is very difficult to prove myocardial infarction if the accident is fatal with disintegration of the aircraft and crew, the statistics are easier to understand.

A frequent cause of incapacitation in the air is the acute onset of disabling anxiety. While there is little to be found in the literature to support this statement, personal and anecdotal experience of the writer suggests that this is a common cause of acute incapacitation in the air. A number of studies have shown that psychiatric causes account for about 50 percant of permanent disqualifications of aircrew in

professional aviation. As with the other potentially incapacitating problems, the large majority of these come to attention on the ground and are dealt with before a critical situation in the cockpit occurs. Although the disabling anxiety attack in the air is often sudden in onset, and there may or may not be an immediately precipitating factor, there is usually a history of increasing uneasiness in the air on flights preceding the one on which decompensation occurs. The history and circumstances which frequently lead to an incident of this type are often so typical that with the "retrospectoscope," it can often be said that the incident should have been predicted. This disabling anxiety is often the culmination and consequence of a number of stresses in the life of a pilot who has a particular personality makeup. Unfortunately, unlike many other causes of partial incapacitation when decompensation does occur it is often very difficult to resolve. One of the reasons that it is difficult to get statistics on anxiety as a cause factor of incapacitation is that it almost invariably leads to hyperventilation. The symptoms of the hyperventilation overlie and interact with the anxiety symptoms so that it is often classified as hyperventilation. The real underlying cause is sometimes, but not always, uncovered at a later date. This is only one of the numerous examples of inadequacy and ambiguity which exists in the classification of human factor causes of accidents and incidents. Aviation medicine lags far behind the pilots and engineers in clearly defining and assigning cause factors, which makes any study of physiological psychological accident/incident statistics difficult.

It is noteworthy that hyperventilation is listed under all five categories. By definition, hyperventilation is always secondary to some other precipitating factor. Hyperventilation may be associated with hypoxia; with pain related to barotrauma or a kidney stone; with anxiety; with self medication as in salycilate toxicity; with airsickness or almost any other cause listed in Figure 31. The symptoms of hyperventilation have been discussed earlier and these should always be looked for when investigating an incident of incapacitation in flight. A very simple hyperventilation test where the airman is asked to deep breath once every two seconds for 30 seconds will elicit symptoms in most cases. Usually aircrew will readily recognize these as symptoms that they have experienced in the air. When it is established that the pilot was hyperventilating this should immediately lead to a further search to determine why he was hyperventilating.

Otitis or sinus barotrauma are undoubtedly the most common physiological symptoms experienced in flight. While this is an infrequent cause of incapacitation to the extent that safety is compromised it may on occasion result in pain of such intensity that it distracts and degrades the pilot's performance. Rayman (7) reports two incidents of otitis barotrauma resulting in fatalities; one incident was associated with otitis media and another with an overpressurization problem. The important aspect of this problem is that it is almost entirely predictable and therefore preventable.

Acute gastric upset with nausea pain and/or diarrhea of undetermined etiology or related to food poisoning is a common cause of sudden incapacity in flight. Although these conditions occasionally become a real threat to flight safety, they are usually only mildly incapacitating and sometimes nothing more than extremely embarrassing. Considering the places that military pilots eat, the types of food they often consume and the quality of in-flight nutrition sometimes provided, it is surprising that food poisoning is not a common cause of incapacity. It is likely that these factors are so accepted as a normal part of the military pilot's life that they are significantly underreported.

Muscle cramps do not really classify as minor illnesses; however, they are included because they can be a serious problem in a fighter cockpit. In order to relieve a cramp, the cramping muscle must be stretched and this is often impossible for a pilot strapped into a cramped cockpit. The combination of muscle tensing, to resist "G" with extreme heat stress, can be a precipitating cause of muscle cramps.

In capacitation due to the ingestion of drugs that are prescribed or otherwise, is a very real cause of incapacitation. Despite everything that is done to teach aircrew about the dangers of using medication while flying, they continue to medicate themselves with such things as antacids, salicylates, codeine, caffeine, decongestants and antihistamines. The effects of some or all of these drugs are potentially compounded by most or all of the flight stresses. Moreover, despite a relatively rigid training system, all too frequently physicians both within and outside the military prescribe medication to aircrew without adequate consideration of the consequences. The ultimate control over the ingestion of any medication is the airman, and the solution of this problem lies in indoctrinating him to <u>not fly while medicated</u>, and to question any physician who prescribes him medication when he is on flight status.

Probably the most important drug involved in partial incapacitation in the air is alcohol. Once again, it is not possible to substantiate this statement by literature reports or any other documentation because of the sensitivity of the issue. The effect of a blood alcohol level and hangover on performance is relatively indisputable, as is the role of alcohol in general aviation accidents. However, reports on alcohol related military aviation accidents and incidents are sparse. One of the reasons for this is the difficulty that exists in defining when degraded performance becomes partial incapacitation. Professional military pilots are usually very conscientious about alcohol and flying, but less so about hangover, and usually have a poor understanding of hangover effect.

One area where alcohol is often associated, is in the pilot who experiences disabling anxiety in the air. It may be difficult to determine whether the pilot has become anxious because his performance is chronically impaired by alcohol or whether the alcohol is being used to relieve the existing anxiety related to flying. By the time the crisis occurs in the air the two factors may be inseparable. The disease alcoholism is listed under the psychiatric category only because of a lack of a better place to put it.

Neurological conditions are an obvious potential cause for incapacitation; however, the serious neurological conditions which could result in catastrophic events in the air are extremely rare and quite unpredictable. Two neurological conditions which are relatively common in this age group are migraine and epilepsy. Of 36 incidents of LOC in flight reported by Rayman (7) in the USAF over the five year period 1966 - 1971, 8 were attributed to seizure disorders; in his later study covering an 11 year period, 4 others have been attributed to seizure disorders. This would have to be considered an alarming statistic because there is no event more critical in the cockpit than a seizure. A seizure almost certainly would be fatal

to the pilot flying alone and very dangerous even in a multiplace cockpit. It is an unfortunate fact that at the present time it is simply impossible to screen out all of those who have a low seizure threshold. In the Canadian Forces there has not been a documented incident of a seizure in the air; however, a number of aircrew have had seizures on the ground. Some of these have been related to alcohol abuse and were therefore preventable. Once again either poor documentation or chance appears to play a role in the statistics. It is worth remembering at this point that seizure type activity can be observed with any hypoxic insult to the brain and can be seen in association with hypoxia, hyperventilation, decompression sickness, myocardial infarction, or syncope due to any cause. Loss of consciousness due to acceleration stress is often followed by convulsive type activity, but a seizure can usually be readily ruled out as a serious concern with a proper history.

Migraine is a common, episodic, sometimes unpredictable and potentially incapacitating disorder; however, it is an unusual cause of incapacitation. In the 15 year period covered by Rayman's reports (6, 7) only one case of incapacitation was attributed to this cause. Although migraine rarely causes loss of consciousness, there may be a significant number of partial incapacitations due to migraine which go unreported. However, the high incidence of the problem and its natural history are such that when it does occur it usually comes to the attention of the flight surgeon on the ground and the pilot is either disqualified or restricted.

Just as in the general population, there are military aircrew who are particularly susceptible to vasco-vagal syncope, or simple fainting. Vaso-vagal syncope/fainting is almost always secondary to some clearly defineable emotional or physical cause. While some aircrew may experience recurrent fainting on the ground, when syncope associated with acceleration stress is excluded, there are no reports of this occuring in the air. This may be the result of the aircrew selection process. Simple fainting which occurs in predictable and avoidable situations should not create a problem in the air. Recurrent fainting for which no clearly defineable precipitating factors can be determined, is potentially incapacitating in the air and is normally disqualifying.

With the exception of those incapacitations due to causes listed under the "Major Illnesses" category, which are largely unpredictable, virtually all other incapacitations are preventable. Those due to flight stresses are either avoidable, or they are the consequence of an aircraft system or life support equipment failure which should be avoidable. Those incapacitations occuring as a consequence of factors listed under the other three categories almost without exception could be prevented either by the airman and/or the flight surgeon, and those which do occur, reflect some failure on the part of aviation medicine personnel to properly indoctrinate the aircrew and ensure that they are fit to fly.


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The ideas and opinions expressed in this article are entirely those of the author. In those areas dealing with altitude, acceleration, disorientation and vision the facts presented are not original, but based on fundamental principles and precepts widely accepted in the general literature and therefore no credits are given. Figures 2, 5, 6, 9, 10, 11, 12, 17, 18, 19, 20, 23, and 25 are taken from Aviation Medicine Vol I, Physiology and Human Factors edited by Dhenin and Ernsting, and are used with the kind permission of Tri-Med Publishers Limited.

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## REFERENCES


1. Ernsting, J., Prevention of hypoxia - Acceptable compromises. Aviat. Space Environ. Med 49(3), 1978, 495-502.

2. Ellis, J.W., Jr., and J.S. Currie. Cerebral accident subsequent to G-force loading: A case report. Aviat. Space Environ. Med 50(4), 1979, 399-400.

3. Bauer, L.H., Symposium on blind flying. The Journ of Aviat Med Vol 1, No. 3, 127-153.

4. Ocker, W.C., Instrument flying to combat fog. Scientific American, December 1930, 430-432.

5. Rayman, R.B., In-Flight Loss of Consciousness. Aerosp Med 44(6), 1973, 679-681.

6. Rayman, R.B., Personal Communication.

7. Rayman, R.B., Sudden Incapacitation in Flight 1 Jan 1966 - 30 Nov 1971. Aerosp Med 44(8), 1973, 953-955.

8. Mohler, S.R. and C.F. Booze., U.S. Fatal general aviation accidents due to cardiovascular incapacitation: 1974-75. Aviat Space Environ Med 49(10), 1978, 1225-1228.

9. Rayman, R.B., Myocardial Infarction: An in-flight problem? Aerosp Med 45(1), 1974, 86-89.

10. Dehnin, G., Sharp G.R., and Ernsting, J., Aviation Medicine Volume 1 - Physiology and human Factors, London, Tri-Med Books Ltd 1978.

# - HUMAN FACTORS -

by

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## SUMMARY

The complex relations of factors causing man to fail in military aviation are reduced to a simple model. Basic connections between the several components of a controller, computer and decision-maker are drawn and applied step by step to the aviator's conditions. Man's abilities and qualifications for the perception of cues are discussed, their importance in the field of aviation indicated. The importance of human engineering, display and control design including information presentation is related to aviation; basic principles for the development of future design are listed.

Physiological factors and their importance on pilots'performance capabilities as well as psychological factors like alterations in attention, arousal and motivation, and the aviator's need for decision-making are discussed. Problems of aircrew selection, crew monitoring, crew training and performance supervision, in combination with suggestions for improvement, and an accident-zone-model, based on a recent study within the GAF, conclude this composition about 'Human Factor Aspects' of aircraft accidents.

## INTRODUCTION

The numerous aircraft accident statistics which have been published by civil and military authorities over the past ten years reveal one common remarkable trend. The percentile-share of the so-called Human Factor in the origin of aircraft accidents steadily increases, independantly from an increase or decrease in absolute accident figures. At this time, human failure is the most frequent cause of aircraft accidents, accounting for 80-90% of all accidents in military aviation. To explain or evaluate the reasons for this fact one could present two theses, as pointed out in "Abriß der Flugpsychologie" by Dr. K. Gerbert:

1st Thesis: "The reliability of aircraft and its subsystems has become greater.
2nd Thesis: The reliability of pilots has become rather smaller."

There are indications that both theses are pertinent, and the relative increase in human factor accidents in aviation is of necessity the consequence of an increasing discrepancy between technical and human reliability. Obviously man can guarantee the functional safety of technical system components to a great extent but is rather marginal in the effort to keep his own action- and reaction control within safety limits. This is particularly true if he has to keep up certain required qualities under demanding situations.

That exactly seems to be the weak point of man, since several a c t u a l psychophysical variables determine the fitness to fly, especially if extraordinary situations occur. The problems of accident investigation are determined by the complexity of conditions combined with relatively small numbers of evaluable happenings. It is therefore necessary to simplify the components and their correlations and effects by the establishment of a base model. Having understood the basic model it is then possible to indicate more relevant significant correlations and examine their effects on aircraft incidents or accidents. Over a certain period of time it will then be possible to establish detailed improvements and assess their effectiveness on safety.

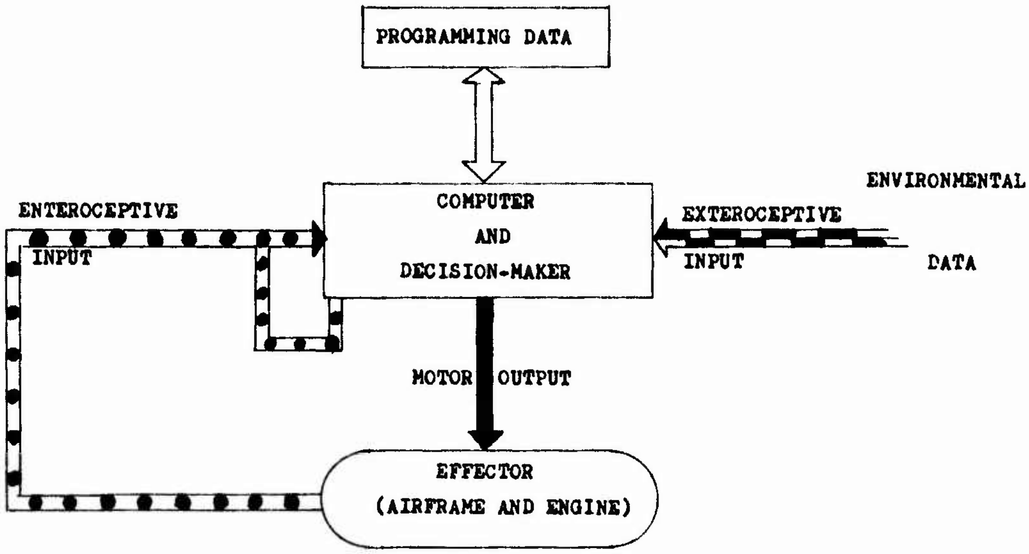
## 1. BASIC MODEL OF MAN-MACHINE SYSTEMS

Flight by man is basically a result of his ingenuity to overcome his physical inability to sustain himself in the air unaided. Fundamentally, this has been accomplished in two separate steps:

(1) By observation and analysis of nature, followed by experiments to surpass the effects of gravity. The development of hot air and gas ballons followed by the use of airfoils was the logical consequence.

(2) The development of technical systems for voluntarily, aimed steering of aircraft, which made him independant of his physical deficiencies.

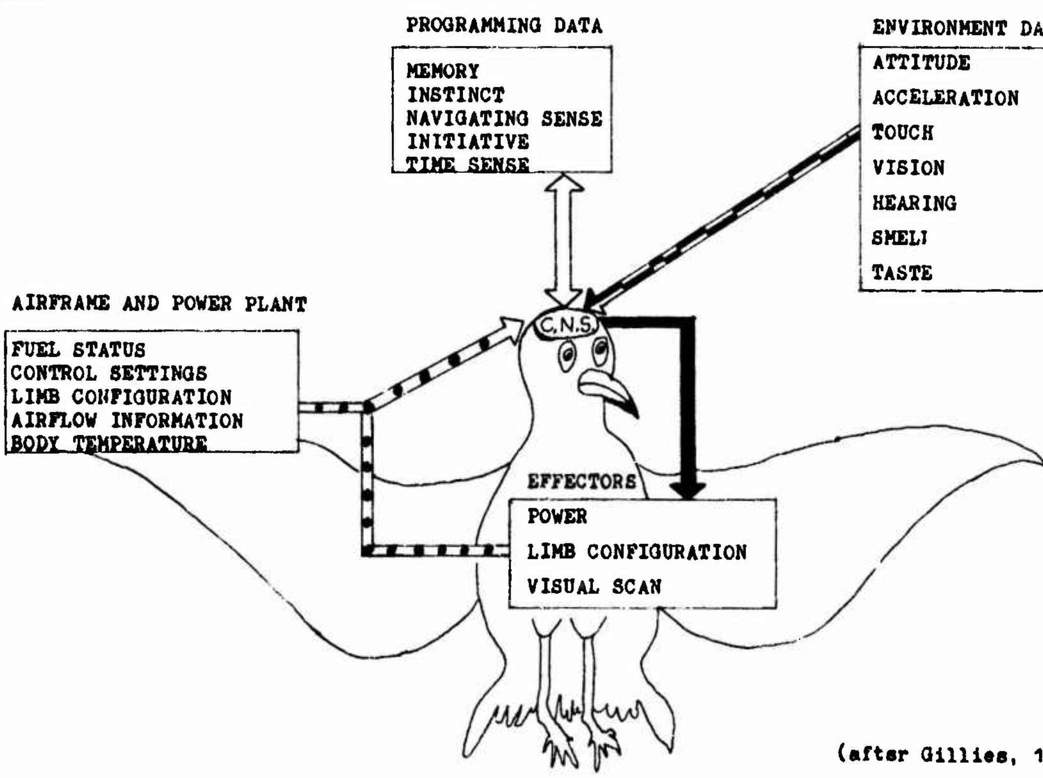
Birds have developed their ability to fly over a much longer time-span than man and although these natural fliers occasionally have accidents, they are very rare ignoring accidents between birds and man-made technical apparatusses.
It is then profitable for man to make a serious comparison between the evolution of flying creatures and the development of powered flight and thus to determine in what manner the processes of natural selection have provided solutions to the multitude of problems that are associated with flight.




(after J.A. Gillies 1965)

Figure 1. Lines upon which comparisons between winged vertebrates and the human aviator can be based.

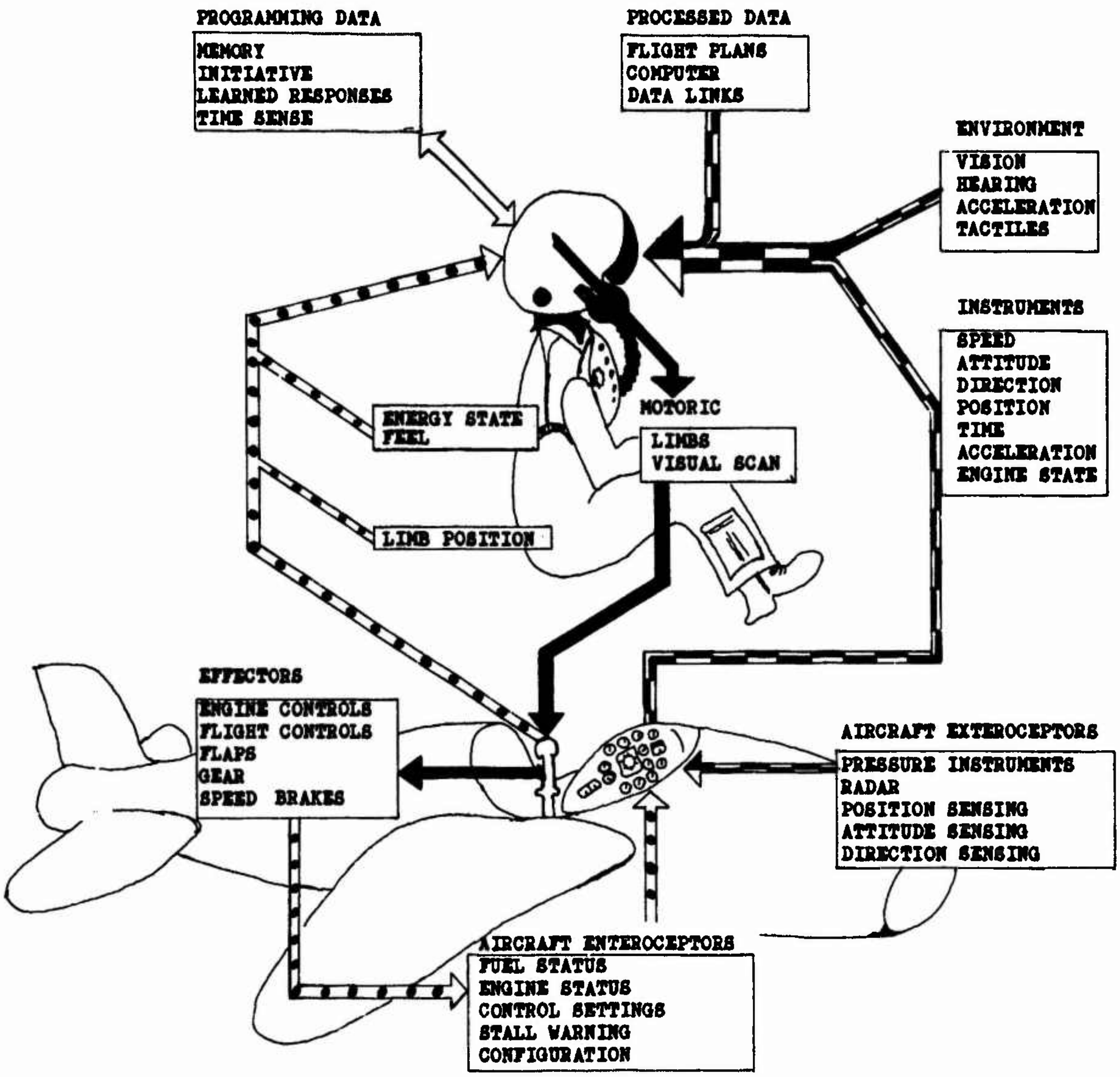
A computer and decision-making device serves as a control complex. It receives two types of input, which have been termed by Sherrington as "enteroceptive" and "exteroceptive" inputs. The former is concerned with the state of the effector apparatus and the computer itself, whilst the latter provides data about the external environment. The two types of input are assessed in terms of certain reference data which are responsible for "programming" the whole activity of the computer, and which are, at the same time, subject to continuous review and modification.
From the computer an output of signals controls the effector apparatus, and thus exercises control over effectors in accordance with three inputs: programming, exteroceptive and enteroceptive.
In accordance with the basic concept above, relations can be analized in a natural flier, the bird.




(after Gillies, 1965)

Figure 2. Analysis of the functions of a bird based on concept of Fig. 1

Advantages and disadvantages of this kind of concept can readily be seen.
In the area of programming data memory, instinct, navigational sense, etc. are relatively rigid, i.e., they can hardly be modified, so if external conditions change, adaptation to modified conditions is nearly impossible. Errors or failures often result in serious consequences (i.e. migration habits to meanwhile dried-up waters).
The abilities to perceive information about the environment are remarkably well developed and superior to those of man. The greatest advantage of the natural flier lies in the integration of necessary components for flight and landing within its own body, its compactness.
If an analysis of man-controlled aircraft is attempted in similar terms, the result is a rather complex diagram such as shown in Figure 3.




(after Gillies, 1965)

Figure 3. Analysis of the functions of a man-controlled aircraft based on concept of Figure 1

From these obviously over-simplified diagrams one could easily derive the following conspicuous characteristics:
Man lacks many of the bird's direct sources of information. His proprioceptors tell him about the position of flight controls but give little information about the actual position of the control surfaces. Data such as speed, airflow conditions, altitude, and landing gear position have to be fed to him via instruments, each of which must be scanned, interpreted and checked for satisfactory operation before he can apply the knowledge gained therefrom.
Similarily, he has no direct information about fuel status, power-plant efficiency and general airframe stressing and he has to rely on visual indicators and inadequate auditory cues. He certainly has no sense of direction comparable to the navigational sense of birds, and none of the "instinct" for flight control.
Of his sensory systems, man's visual apparatus is the most heavily overtaxed and it has to supply the brain with most of the information about the aircraft, in addition to exercising its normal

exteroceptive functions.
The proprioceptive system supplies information derived from the machine and its control system and it must be constantly monitored in order to suppress the previously learned meanings of much of the information, and so allow the more recently learned interpretations to be made.
The higher centers linked with the vestibular apparatus are of limited value in that they are often faced with the task of interpreting conditions not encountered as part of everyday life.

On the credit side, man has the aid of ground controllers, radar, navigational instruments, computers and indicators, which give him accurate information as to attitude, altitude and speed. By these means he has been able to excel the birds in some respects, whilst generally lacking sadly in terms of reliability, maneuverability, landing and take-off performance and, above all, in compactness.
He is always hampered by the time-lag, the relative inefficiency and the irregularity of behaviour inherent in the adoption of the complex sequence of linked operations, which is needed in carrying out any of the component tasks of man-made flight.
His work load is always further increased by the need to inhibit many previously established interpretations of information and to superimpose on them the interpretations learned by training as an adult.
All this is an environment to which many of his senses are poorly adapted and in which his visual system, decision-making powers and memory are completely occupied, if not overtaxed.
Having established, in broad terms, the principles upon which the man-aircraft relationship is based, it is important to ascertain the ways in which the system fails, the categories in which this is most likely to occur, and the underlying factors and conditions which may increase any existing weakness.
Using the already discussed approach it follows that, when failures occur in the man-machine complex, they can be attributed to shortcomings in one or the other of the following four components.

(1) The human exteroceptive system.
(2) The input from the aircraft exteroceptive and enteroceptive systems.
(3) The higher centers of the central nervous system including psychological factors.
(4) The effector output from the central nervous system.

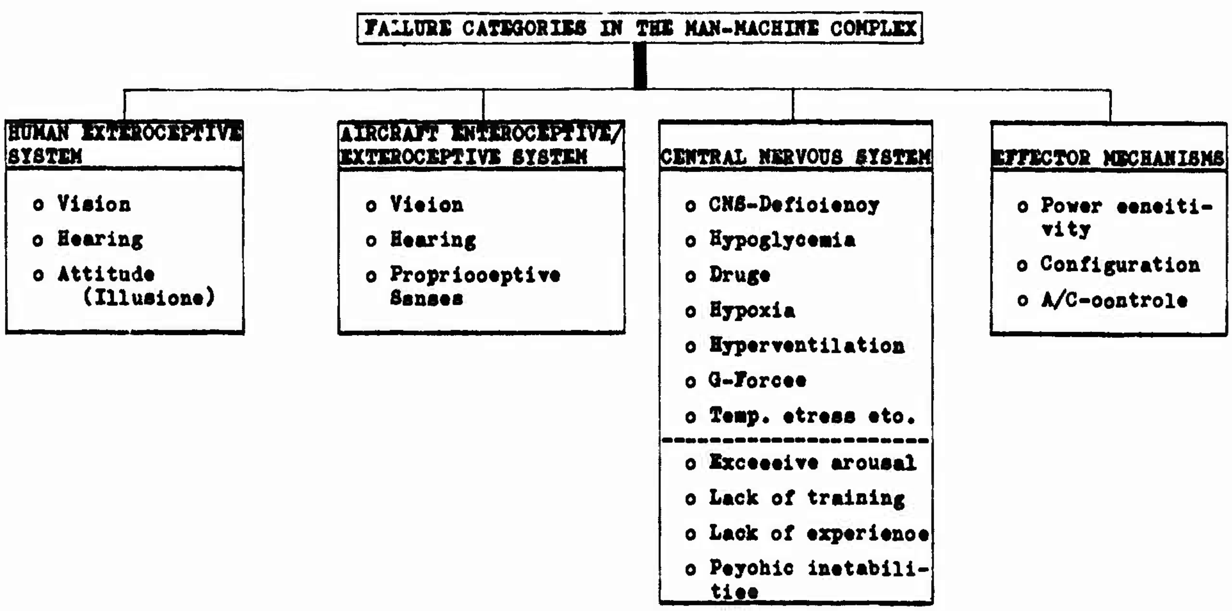



Figure 4. Possible failures in the categories based on concept of Figure 3

2. PERCEPTION FACTORS

As we have already seen, the human exteroceptive system is one of the most important and mostly stressed part of the aviator's abilities. It is very important to stress, that the meaning of any pattern of stimulation is a personal matter and depends upon the perceiver as much as upon the nature of the stimuli.
At any given moment we are surrounded by literally thousands of external stimuli and subjected to a large number of internal stimuli as well.
The process of attending enables us to focus on certain ones of these stimuli and to ignore others. Those we do attend to, however, must be organized into meaningful patterns to permit us to interpret them and to respond to them. An erroneous perception may result in an error of response.
Stimuli are physical forces and energies, whose dimensions can be measured. What these forces and energies mean to us individually, however, depends not only upon their physical characteristics but upon the physiological and psychological characteristics of the perceiver. To be brief, the following three factors determine the quality of perception:

(1) The nature of stimuli.

(2) The characteristics of the special senses which translate stimuli into nerve impulses.

(3) The past experience and present condition or attitude of the perceiver.

In general there are two types of perceptual errors. First, there are those resulting from the observer's failure to correctly identify the stimulus patterns he has received. In the second category are the illusions, i.e. experiences in which perceptions can be demonstrated to differ from reality or to be distorted. These two error categories will be covered later and in connection with the discussion of Spatial Disorientation.
The third factor is the built-in human time-lag.
Due to the enormous speeds and the tactical requirement to fly as low as possible, it is sometimes impossible to perceive a certain object, even if illumination, contrast, shape, etc. are well within the perceptability range. Figure 5 shows the elapsed times from first sighting to the change of flight path.

| OPERATION | TIME (seconds) | |
|---|---|---|
| | For operation | From sighting |
| SENSATION (light travels from retina to brain) | 0.10 | 0.10 |
| MOTOR REACTION (preparatory stage for eye movements) | 0.175 | 0.275 |
| EYE MOVEMENT | 0.05 | 0.325 |
| FOCUSING WITH FOVEA | 0.07 | 0.395 |
| PERCEPTION (minimum recognition) | 0.65 | 1.045 |
| DECISION-MAKING (estimated) | 2.00 | 3.045 |
| OPERATING THE CONTROLS | 0.40 | 3.445 |
| A/C CHANGES FLIGHT PATH | 2.00 | 5.445 |

FIGURE 5. Perception - operating and elapsed time.

The sensing time is a function of the properties of the signal, its size, intensity and duration, and of the sense through which it is presented.
The perceiving time is a function of the complexity of the signal as it must be interpreted before a decision can be made, once the stimulus has reached the brain.
The decision time is a function of the complexity of the situation. When no decision is required, the delaying effect is small, but when a decision is required in a more complex situation, the lag is increased.
The response time is a function of the complexity of the response; the position of the control, the force required to operate it, the amount of displacement and the limb which must be used.
As time-lag depends upon the complexity of the situation and the number of possible responses, delays can be reduced if the situation is simplified and the operator trained. Figure 6 shows the significance of this problem in respect to high speed-, low level flight.

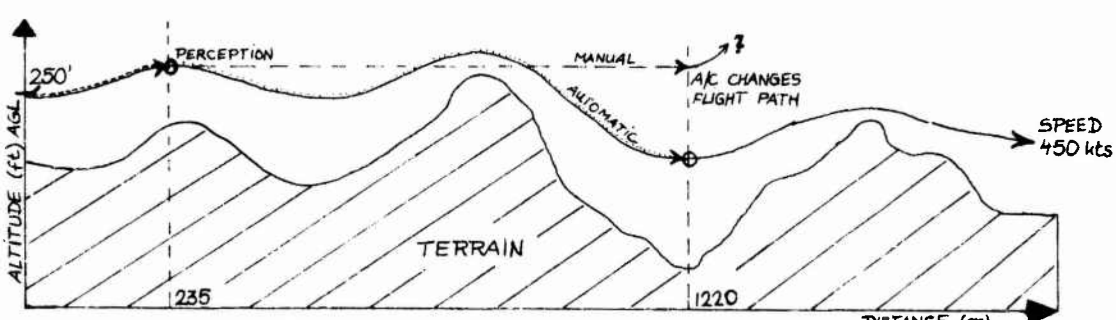



Figure 6. Perception and low level flight

At a speed of 450 kts a pilot could react to obstacles or terrain features only if they are more than 1.22 km away. If speed is to be increased and furthermore altitude decreased, as it will be required in actual combat situations, the human performer is overtaxed. Using his natural senses, he is unable to precisely navigate or avoid obstacles. Therefore the MRCA-Tornado has an automatically controlled terrain-following-system, coping with the problems but making the pilot an inactive sufferer, with the consequence of increasing psychological stress. A change of selection- and training criteria seems to be imperative.

But even at low speeds, as in precision approaches (GCA) combined with marginal weather conditions, aviators are sometimes pressed into the dangerous corner of lacking time for alternatives.

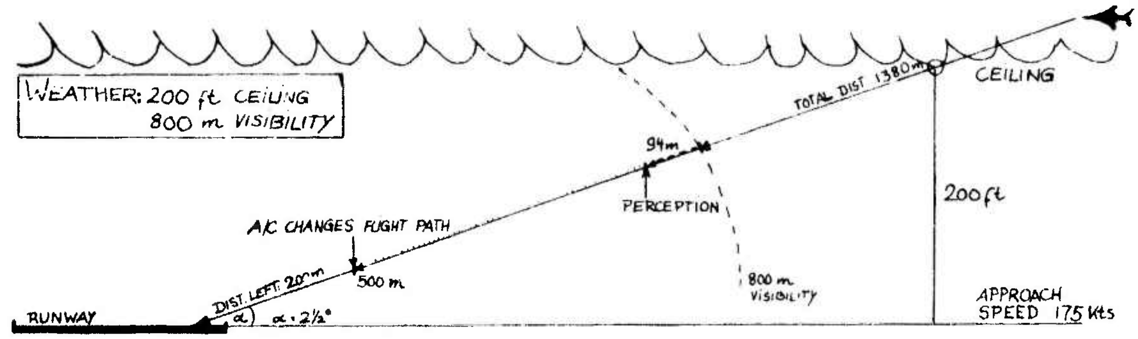



Figure 7. Perception and precision approach.

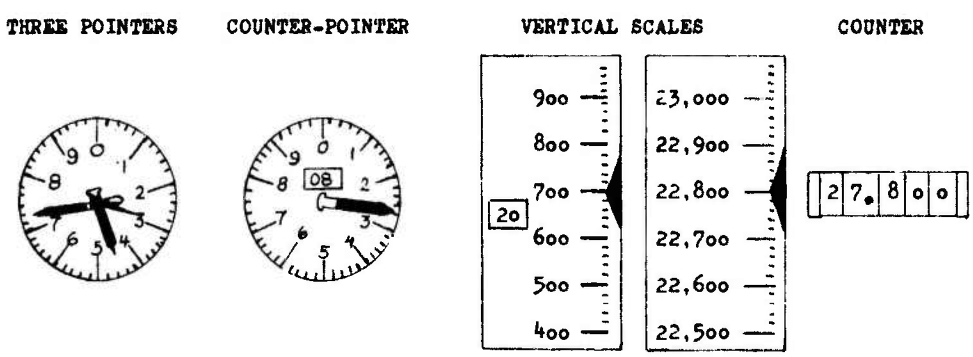
Figure 7 shows a final approach with a 2 1/2 degrees glide path under critical weather conditions with a ceiling at 200 ft and visibility of 800 m, which are allowed minima to continue the approach for combat-ready pilots in the GAF.
There is actually neither time nor distance left for more than one correction. With an approach speed of 175 kts the distance covered by the airplane is 94 m, before the pilot can perceive any visual cues from the runway. Bringing the airplane on the desired course covers another 500 m. With a visibility of 800 m there are only 200 m distance left to the runway to furthermore correct for the right position to safely land the aircraft.
Knowing about man's natural limitations, principal considerations have to be made in the construction and cockpit layout perfectly adapted to man.

## 3. HUMAN ENGINEERING FACTORS

Quite a number of perceptual errors could be prevented, if designers of future aircraft could apply "Human Engineering" in the most effective way. But often budgetary reasons, tactical requirements or simply a lack of coordination cause failures in an effort to reach the optimal solution. It would be impossible to cover all aspects pertinent to aviation. Therefore we have to concentrate on the most important aspects and select some examples to demonstrate the importance of aircraft equipment design in the prevention of accidents.

### 3.1 Display - Receptor Relationships

The aviator cannot do a safe job of controlling his airplane if he is not given adequate, accurate and timely information in a form that he can readily understand. (Figure 8 shows possible solutions of instrument design to display altitude and their effects on error probability and interpretation time).




| | | | | | |
|---|---|---|---|---|---|
| PERCENT ERRORS OF 1000 ft OR MORE | 11.7 | 0.7 | 0.3 | 1.3 | 0.4 |
| INTERPRETATION TIME IN SECONDS | 7.1 | 1.7 | 2.3 | 1.7 | 0.0 |

Figure 8, Study in Altimeter Scales (from Grether)

When new information had to be displayed, it was common usage until a few years ago to simply add a new instrument in the cockpit, thus slowly approaching the aviator's limitations in perceiving and interpreting relevant information with sufficient rapidity. Quite often new concepts of how to transmit visual information to the aviator turned out to be worse.

In an effort to reduce the number of instruments - basically a good approach - important relevant information was lost or resulted in multi-function, multi-scale, multi-pointer monstrosities.

As a result of permanent research for optimal aircraft instrument design, the following fundamental psychological principles can be listed:

#### 3.1.1. Spatial Analogue

The aviator needs some kind of a spatial picture which gives him a fixed reference frame, which is essentially non-numerical and in which spatial orientation can be easily visualized with only occasional monitoring.

### 3.1.2. Dimensional Realism of Indices

If something moves in the real world, then the indicator should move. If something is stationary then it ought to stay still in the display. This principle applies to direction as well.
Aviators are used to fixed airplane indicators up to this day but as proven in flight tests moving airplane representation is generally superior.

### 3.1.3. Pursuit Displays vs. Compensatory Displays

How should command steerings be given? Is it better to chase the airplane into a desired performance index (pursuit display) or should the pilot be given a compensatory display in which the signal is an error signal and his task is to "null" the error? Usually the pursuit display is the best. Display movement should resemble the direction of the error itself rather than the direction taken to correct the error.

### 3.1.4. Change of Set

Pilots have to shift their attention from one instrument to another to gain overall information for relevant decision-making (cross-check). To assist pilot's orientation, especially when he is in a high workload situation, it is essential that related displays be interpreted the same way, have the same fixed/moving parts and have about the same scale factors.

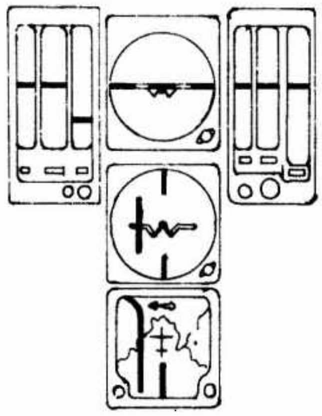


Figure 9. The "T" concept. (The horizontal line represents the forward-looking view, the vertical line the downward-looking view).

### 3.1.5. Symbolic vs. Pictorial Displays

Generally three types of reading functions are served by flight instruments.

a) Check reading for assurance of a normal or desired indication.
b) Qualitative reading for the meaning of a deviation from a normal or desired indication.
c) Quantitative reading for the exact scale value.

Symbolic instruments (dials, pointers) can serve all three types of reading functions. However, it seems to be of advantage to present attitude, rate of turn, geographical position and landing cues by direct vision. The effects are less training, easier interpretation and fewer interpretation errors. The development of head-up displays is one step in the proper direction. By application of miniature electronic equipment improvement is still possible.

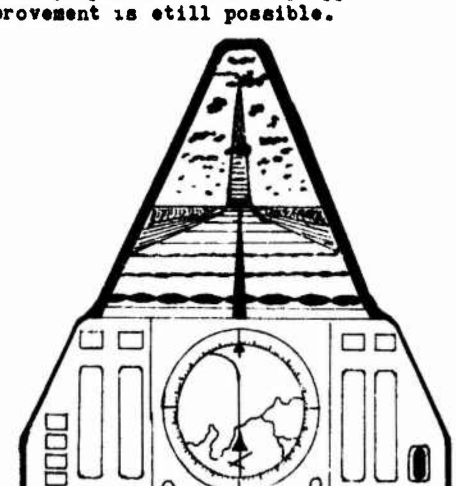


Figure 10. Advanced Pictorial Display

3.2. Effector Control Relationships

The pilot is capable of remarkably fine control, if the control system he works with has been properly gauged to his characteristics.
Some of the most important principles are listed below.

(a) Population Stereotypes

Control movements in aircraft should be in the same plane and in the same direction as in everyday life.

(b) Control Coding

The reason for coding controls is to make them easy to identify. Proper identification is important, not only for preventing activation of the wrong control but for lessening negative transfer when the operator has to change from one control arrangement to another. The primary coding methods are by shape, size, location and color.

(c) Control Forces

The forces which should be considered here are those exerted by the operator of the control and the opposing force of the control itself. Both aspects are necessary in control systems and provide a substantial part of the so-called internal feedback used by an operator of a control device.
The degree to which such forces are discriminable over a wide range of movement is an important limiting factor to the efficiency of operation of any control along with others such as strength, speed and fatigue.
For the airplane stick the force at and above which the ratio of the error and the force to be reproduced becomes constant and small has been found to be ten pounds.
In modern aircraft control forces are adjusted so that when they are operating in regions of poor sensitivity, relatively large increments of force are required to accomplish a given movement and when operating in regions of better discrimination correspondingly smaller increments of force are required for that same movement.

3.3. Control-Display Interrelationships

In design and displacement of control/display elements the following principles should be applied:

- Instruments having the same function should be grouped together.
- The most critical displays and controls should be placed in the easiest-to-see and easiest-to-reach positions.
- Fundamental display and control arrangements should not change from one airplane model to another. This is to prevent inadvertent activations.
- All practicable perception canals should be used. The use of the auditory canal has proven to be very helpful. (On-speed indicator in the F-4, ECM display and audio voicer warning systems like "Leads 2000").
- Frequently used elements should be placed in preferred locations.
- If controls are always used in the same sequence, they should be placed together or even be made foolproof.
- Never display more information than absolutely necessary.

All factors mentioned in Paragraph 3 have been adapted from: " Aviation Psychology" by N.A. Bond et al., published by the Aviation and Missile Safety Division, 1962.
Good Human Engineering is one of the most fundamental considerations in increasing pilots performance capacity, especially in high workload situations, and therefore also an important factor in accident prevention.
Any second gained by excellent aircraft/display design leaves the pilot more time to make the right decision, thus improving the effectiveness of mission accomplishment.

4. PHYSICAL FACTORS

Faulty functions of the higher centers of the central nervous system have already been listed in Figure 4. There are many accidents and incidents in which it is apparent that the sensory system has not been at fault in the perception and transmission of information to the brain, but that the response of the individual concerned has been delayed, absent or incorrect.
Generally the aviator is periodically and intensively checked by the Flight Surgeon or other clinical authorities, so any severe sickness should be detected before it could become a hazard to the aviator. But there are considerations to be made about the actual physical condition of the aviator prior to each flight. Often self-imposed deficiencies are the first link in the chain of events finally leading to incidents or accidents.
Some Warsaw Pact Forces control the actual physical condition of their aviators before they start into their airplanes. This certainly could not be applied to Western Air Forces. Thus Flight Surgeons should stress the importance of absolute physical fitness, making pilots self-aware of the possible disastrous consequences.
In the GAF pilots have to attend courses periodically in connection with their mandatory physical examination. These courses are held by pilots which have additional training including all physiological aspects of aviation.
Deficiencies in the central nervous system could result from the following self-imposed stresses:

- Hypoglycaemia
- Selfmedication
- Excessive smoking
- Hangover
- Fatigue.

These factors may not become a hazard when mission requirements pose no extraordinary stress on the aviator. But as performance demand increases, as in an unexpectedly occuring emergency, or if sensory illusions are present, they can markedly reduce the aviator's abilities to perform and his tolerance to other in-flight stresses. These more specific aero-medical stresses could be:

- Cerebral anoxia
- Hyperventilation

- Decompression sickness
- G-Forces
- Heat stresses
- Noise and vibration.

Since the pilot cannot avoid these stresses, he must at least acknowledge the importance of physical fitness in aviation as one important component of his personal performance capacity. There are direct interfaces between aircraft incidents and accidents and the psychophysiological condition of the pilots concerned.
It would definitely make the pilot's hair stand on end, if the crew chief would tell him that the aircraft he is supposed to fly is a little bit short on gas, the controls might not follow the administered inputs and the electrical system may have some short circuits, but everything else will probably work fine. Figure 11 shows the effects of physiological and psychological components which could serve as a basis to develop training programs, especially for pilots exhibiting a decrease in their total psychophysical performance capacity.
In addition, his actual physical capacity should be checked periodically, using standardized physical load tests with ECG-monitoring.

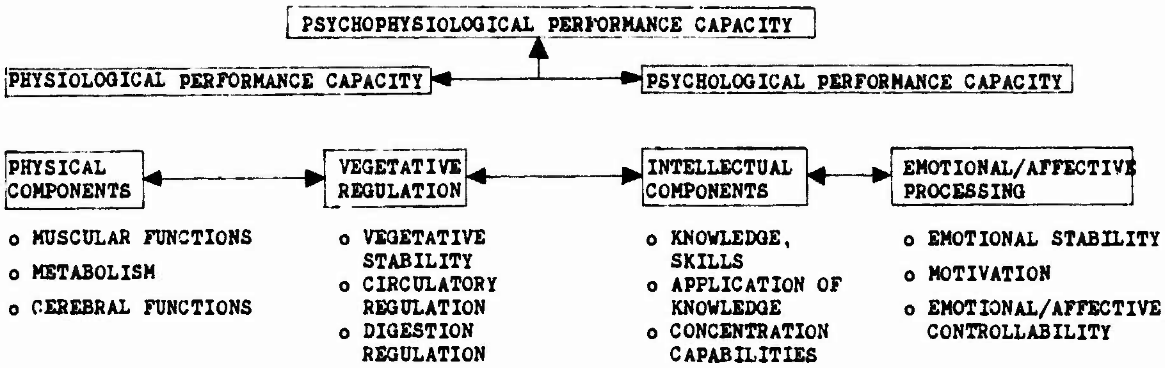



Figure 11. The psychophysiological performance capacity and its linkage

## 5. PSYCHOLOGICAL FACTORS

Psychological capabilities and their influence on performance under difficult side conditions as time pressure, supervisory pressure, fear of failure and a great psychological pressure referring to costly man and material responsibilities are factors determining man's capacity to safely accomplish a given task.
Alterations in attention, arousal and motivation are remarkably often present when failures to appreciate or act upon information occur in spite of an apparently adequate presentation. Thus a fire-warning light may be missed, a low fuel state ignored, a mission continued, even if the prevailing conditions would not permit a successful course of action or a dangerous attitude is acquired while flying on instruments. Figure 12 shows the relation between arousal and performance.

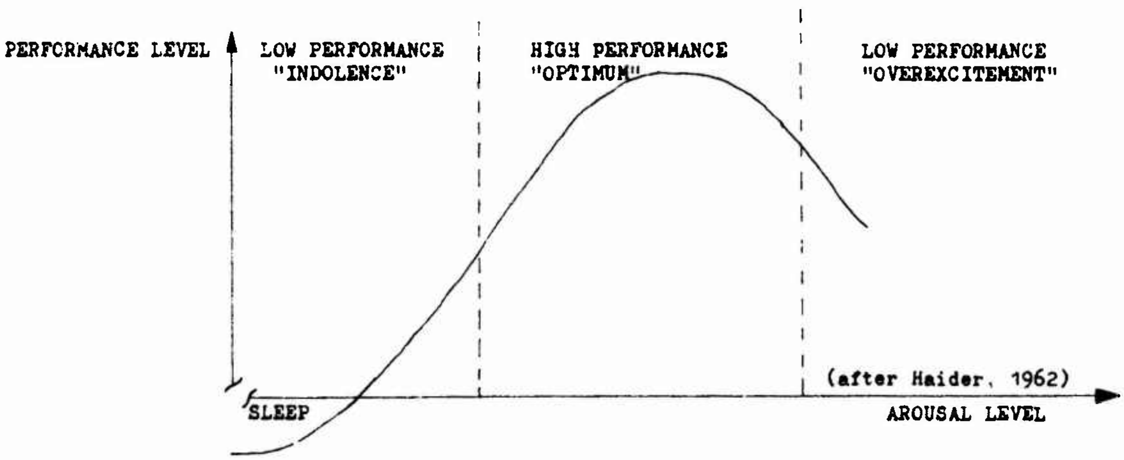



Figure 12. Arousal and performance

As we can see, the ideal prerequisite for a maximum performance would be a constant and relatively high level of arousal not exceeding a certain level. To determine this level and, above all, to qualify pilots to identify the signs and symptoms when this peak level is exceeded or not reached takes a sophisticated crew of psychologists, a realistic simulation of conditions, producing certain changes in arousal and last not least a non-preoccupied pilot.
As there is no progress concerning this field we have to accept the fact that pilots will have to find out about their individual culminating point by the "trail and error method", naturally sometimes leading to disaster. Nowadays pilots are trained for nearly everything, but still lack badly in training their weakest attributes.
Fear and motivation as controlling elements are perhaps sufficient for everyday life, but not for people who have to master technical apparatuses far beyond their natural capacities.

Motivation could be a stimulant for performance, but excessive motivation might even decrease performance capacity to a very dangerous degree. Interfaces between arousal, motivation and performance are presented in the following figure which must be interpreted three-dimensionally!

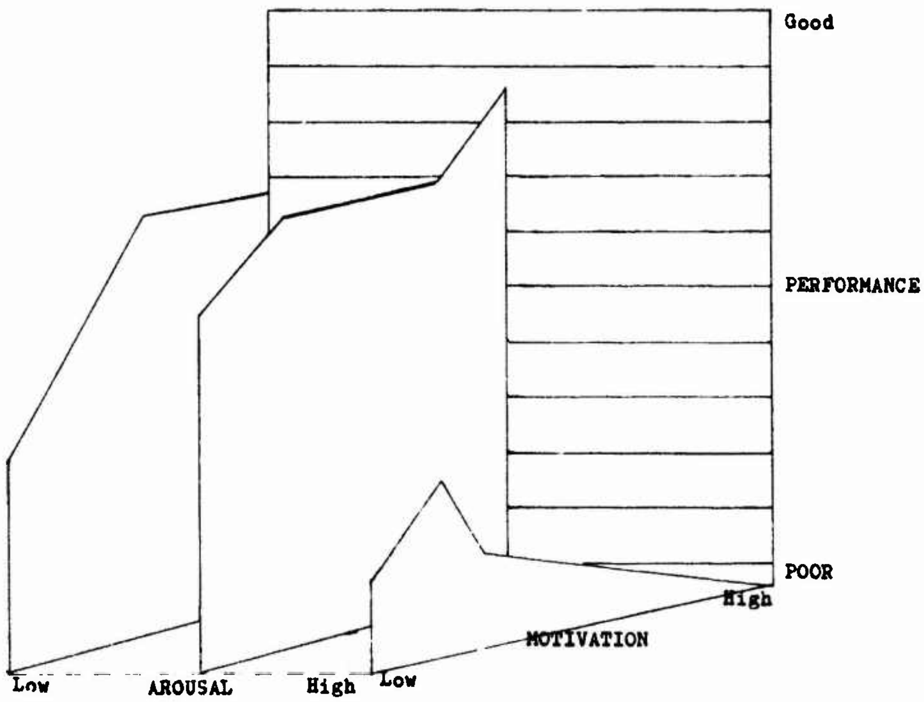



Figure 13. Arousal, motivation and performance

Some examples: A pilot with a low state of arousal and low motivation will not have a good performance capacity, but might develop some reserves if conditions force him to increase motivation (i.e. due to self-preservation in a critical situation) and if the arousal level does not exceed the optimal point, as could happen if he would panic etc.

A pilot might have a medium arousal level approaching the target area. Let's suppose he misses the assigned target. Making a new approach in an effort to definitely succeed in hitting the target, his motivation exceeds peak limits, actual performance decreases and the arousal level may increase rapidly with the risk of exceeding aircraft limitetions and subsequent stall.

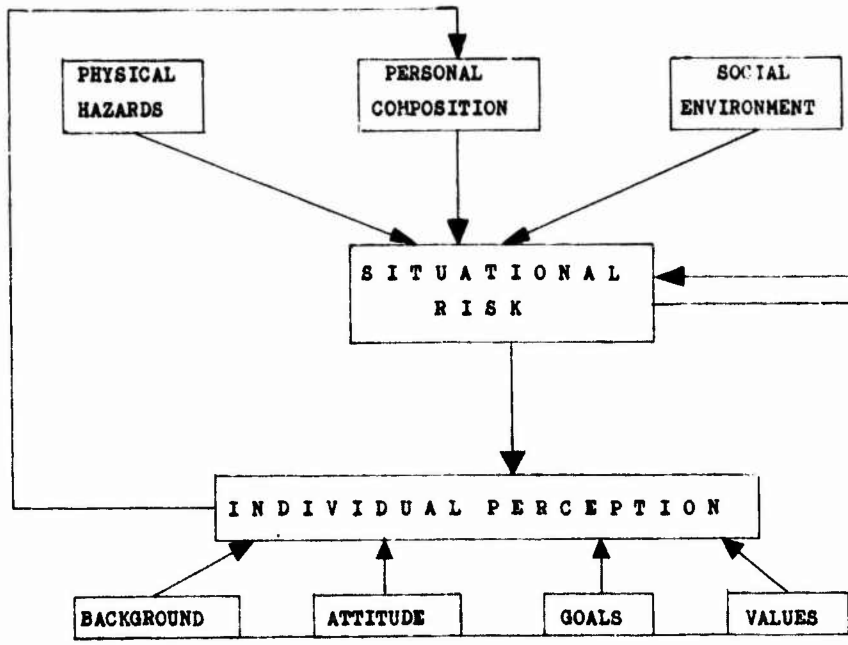
A pilot enters his aircraft after having had personal anger. His arousal level is high, motivation to fly, low. His overall performance capacity is very low. He is a potentially dangerous aviator, since it is very likely that he will commit errors even if no additional performance capacity is required.

A pilot flies a cross-country mission at a very high altitude. Due to lack of visual cues a diminution of awareness of his surroundings results. He gets bored. This is often accompanied by delusions or hallucinations, commonly called the "Break-Off Phenomenon".

Unfortunately, those conditions are almost never questioned in the course of aircraft accident investigations but are most frequently attributing conditions in accidents or incidents, as revealed by a recent study with more than 1400 pilots.
In addition to those more situational conditions, person-immanent conditions which do not change significantly or only over a longer period of time are important to be monitored by appropriate authorities. This is particularly important if:

- A new weapon system is being introduced.
- New mission profiles are demanded.
- A change in pilot's social status or environment has occurred.
- Any personality alterations are observed.
- Any illness followed by a longer period of grounding was experienced.
- A pilot was involved in an accident or incident.

Figure 14 shows the loops concerning the factors mentioned.




(Pugh and Gunderson, 1979)

Figure 14. Situational risk factors

In addition to the failure to respond in accordance with the relevant situation due to ineffective changes in arousal and motivation, deficiencies of reflex response might be the cause for an error. Each alteration in the sensory input during flight must be recognized, assessed and acted upon, whenever necessary, if control is to be maintained.
These responses may be at a conscious level, with reasoning as an intermediate between stimulus and response, or purely reflex without necessarily being consciously recognized. Using these two types of responses, being, in the broadest sense, varieties of established reflex behaviour, different types of deficiency in positive response may be described.

(a) Lack of training represents failure to establish the basis for response, since the latter may be delayed or incorrect, owing to the need to analyze the problem and decide upon a course of action without the help of previous training. This causes the pilot to lose valuable consciousness capacity and time for optimal decision finding.

(b) Lack of experience implies an insufficient opportunity for the establishment of reflex response patterns. The result is either a lack of finesse in handling (poor technique), or a delay or inability in executing a graded response or choice of responses (poor judgment or a slow reaction), which could be either a temporary state or an inherent characteristic of an individual.

The kybernetic model of information flow in humans, as it has been developed by H. Frank, shows the limited capacity of consciousness. The more action programs installed by appropriate training and experience, making actions to a more reflex type of response, the greater the pilot's reserves to deal efficiently with unexpected, rapidely changing external conditions.

The problems of searching for relevant information when pilots are lacking training or experience are due to the fact that they have to use their long-term memory in connection with their consciousness and the appropriate sensory projection- or association centers.
Thus a pilot who has not been flying for more than six weeks will search for switches, has a longer reaction time and, on the emotional side, will feel uncomfortable. Therefore simulator flights and at least one dual flight with an instructor pilot has to be accomplished before he should be scheduled for an actual operational flight. Figure 15 on the next page shows the loops and the capacity of the components concerned, expressed in binary digit numbers.

Most accidents happened because pilots just did not make the right decision and chose a wrong course of action. It is therefore important to determine the characteristics of decisions in flying and the characteristics of the aviator as a decision-maker.
This might lead to a better understanding of the evidence that an aviator did not do what, after the smoke had cleared away, seemed to have been the best thing. Whether anyone could have done better if placed in the same situation often is not certain. Nevertheless, making decisions in the cockpit is a difficult job. In fact, some of the decisions that are required of aviators have been and are beyond human capabilities. But we need man in aircraft, not because he is such a good decision-maker but rather because he is the only true decision-maker we have. We should make the best of his capabilities by providing him with good training and well-designed cockpits.
The more understanding of the characteristics of decisions in flying can be accomplished, the better can his demands be met. Due to the complexity of this problem, which would go beyond the scope of this lecture, the main characteristics are listed as follows:

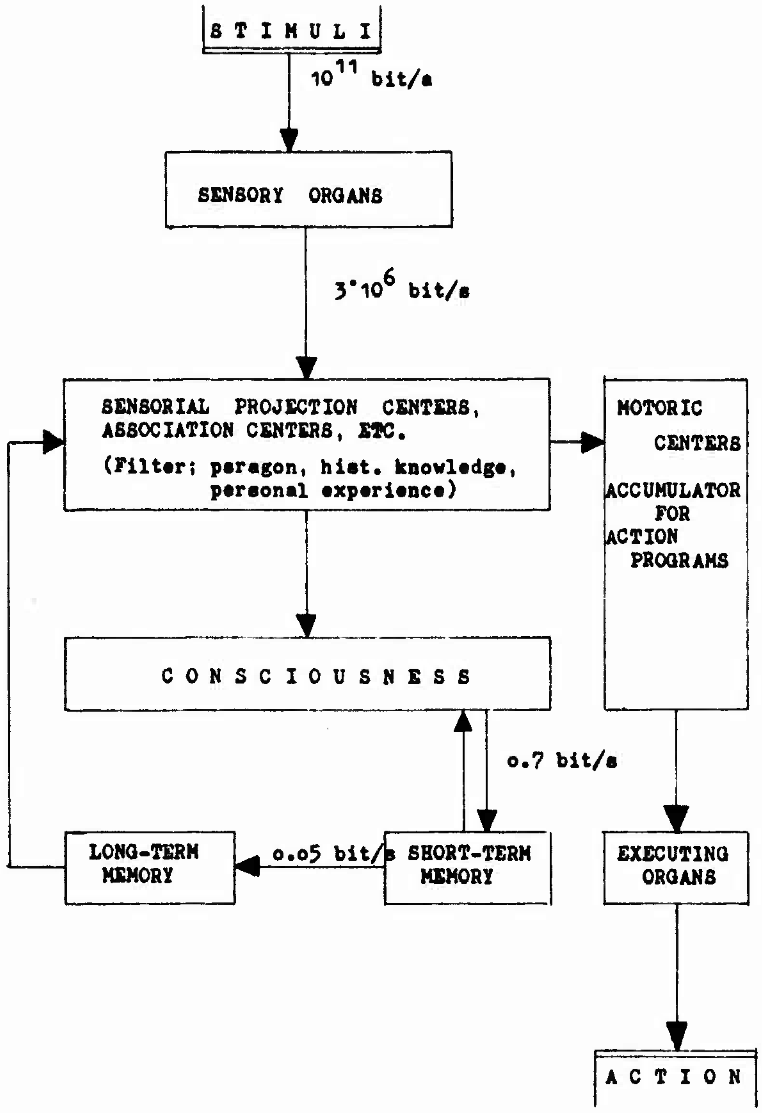



Figure 15. Information Flow Model (after H. Frank)

Characteristics:
- Limited time
- Limited information
- Limited alternatives
- Interdependent alternatives
- Serious consequences.

The characteristics of the aviator as a decision-maker are:
- Flexibility in dealing with events.
- Broad understanding.
- Self-programming

These characteristics are good attributes. But as already discussed before we have to admit that the aviator is mostly vulnerable to distortions like:
- Subjective perception.
- Confusion.

In summary, the best general rules for improving decisions to be made by pilots are:
- Make the decision as simple and automatic as possible.
- Do everything possible to help the aviator anticipate the kinds of decisions he will most probably have to make.
- Provide continuous training and practice in handling the operating situations where judgement is critical.
- Take the particular kinds of decision-making skills required into account when selecting a man and a system for the determined job.

## 6. SPATIAL DISORIENTATION AS EXAMPLE FOR THE COMPLEXITY OF HUMAN FACTOR IN AIRCRAFT ACCIDENTS.

At this point it is practicable to elucidate the previously covered areas by means of an example quite frequently leading to disaster. That is "Spatial Disorientation".
Primarily, orientation is illustrated by Figure 16 on the next page.
Sensory illusions produced by the functional structure of the organs of the inner ear force the pilot to cope with contradictory information, thus degrading his programmed sensorimotor capabilities with the possible result of uncoordinated flight or wrong action programs. Figure 17 shows the curves and components leading to orientation or disorientation.
The psychological effects of changes in the pilot's state of arousal prior to and during flight must be analyzed and added to the physiological problems. Figure 18 shows these effects.

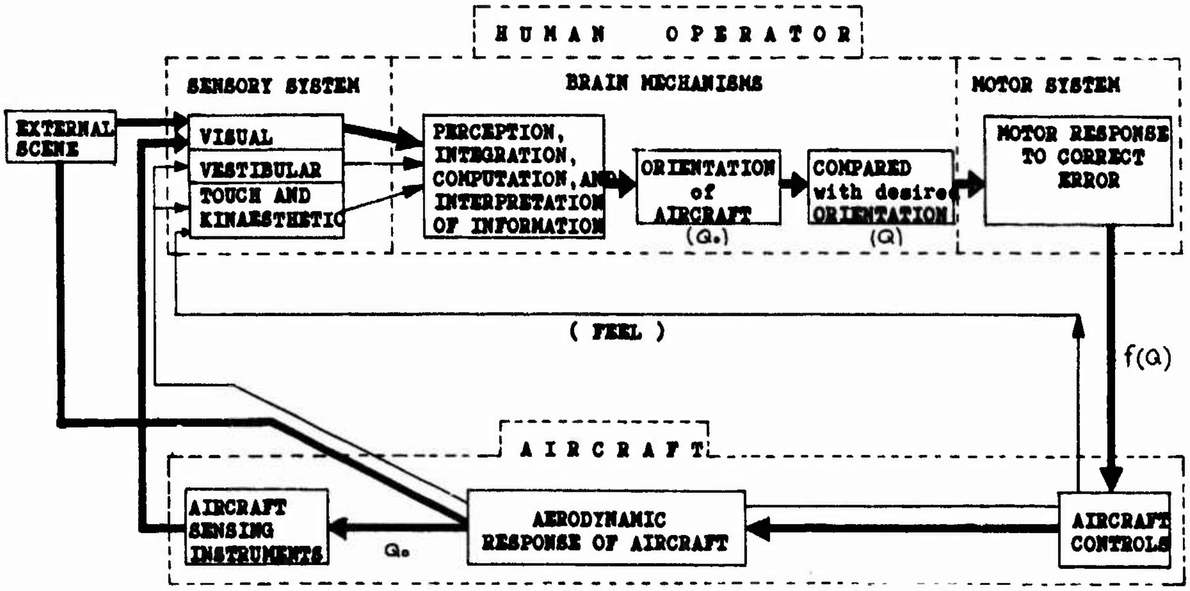



Figure 16. In-flight orientation (after Gillies, 1965)

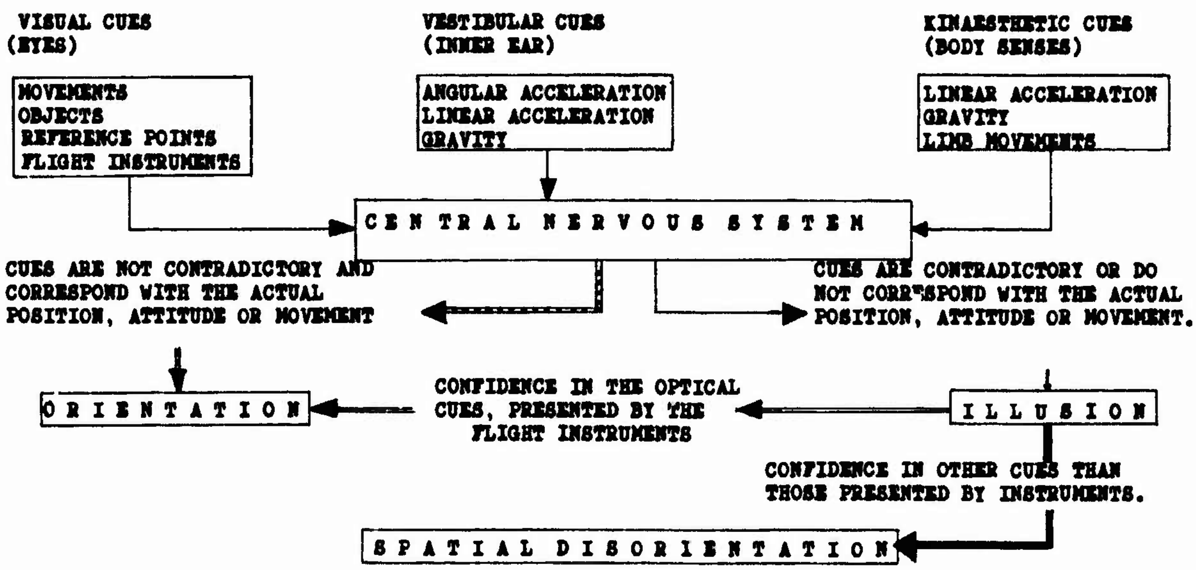



Figure 17. Spatial disorientation in flight

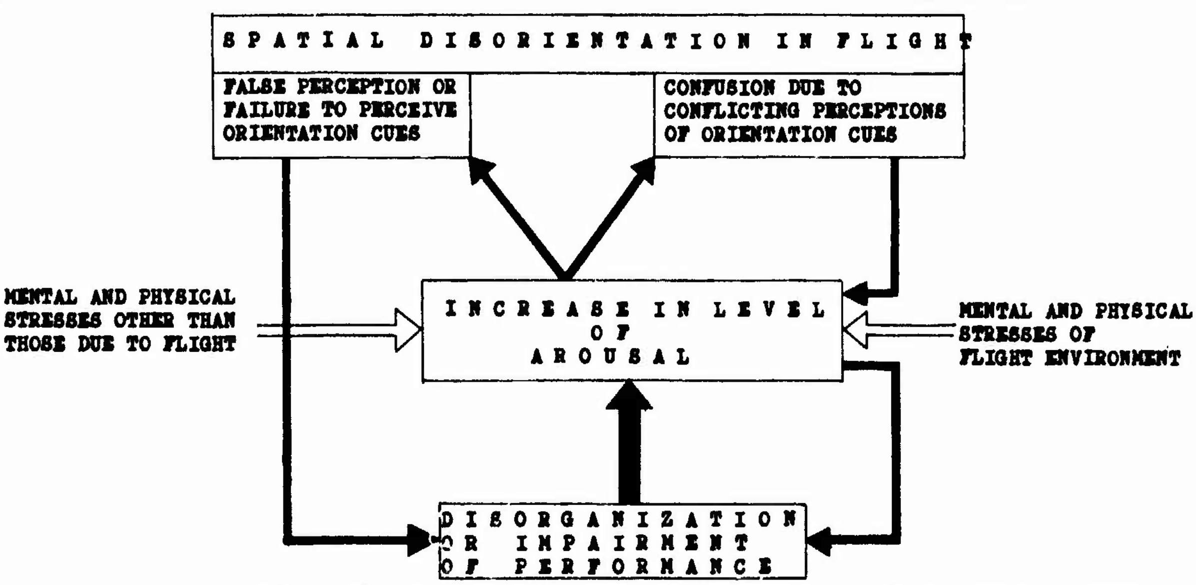



Figure 18. Arousal and spatial disorientation (after Gillies, 1965)

Finally, marginal situational external and internal conditions like bad weather, terrain, physical stressors by the nature of flight (G-forces, turbulence, vibration, etc.), flight order, status of the pilot, aircraft type and psychological factors like excessive motivation to succeed, a lack of risk awareness or imposed supervisory pressure determine the tremendous complexity of factors engaged in what accident figures express in the simple term: "Human Factor".
Figure 19 shows the findings concerning Spatial Disorientation as analyzed by a study recently compiled by the Director, Federal Armed Forces Flight Safety, in cooperation with the German Air Force Institute of Aerospace Medicine. In this figure the frequency of factors is expressed by different size boxes, the interconnections (syndromes) by tied-in lines.

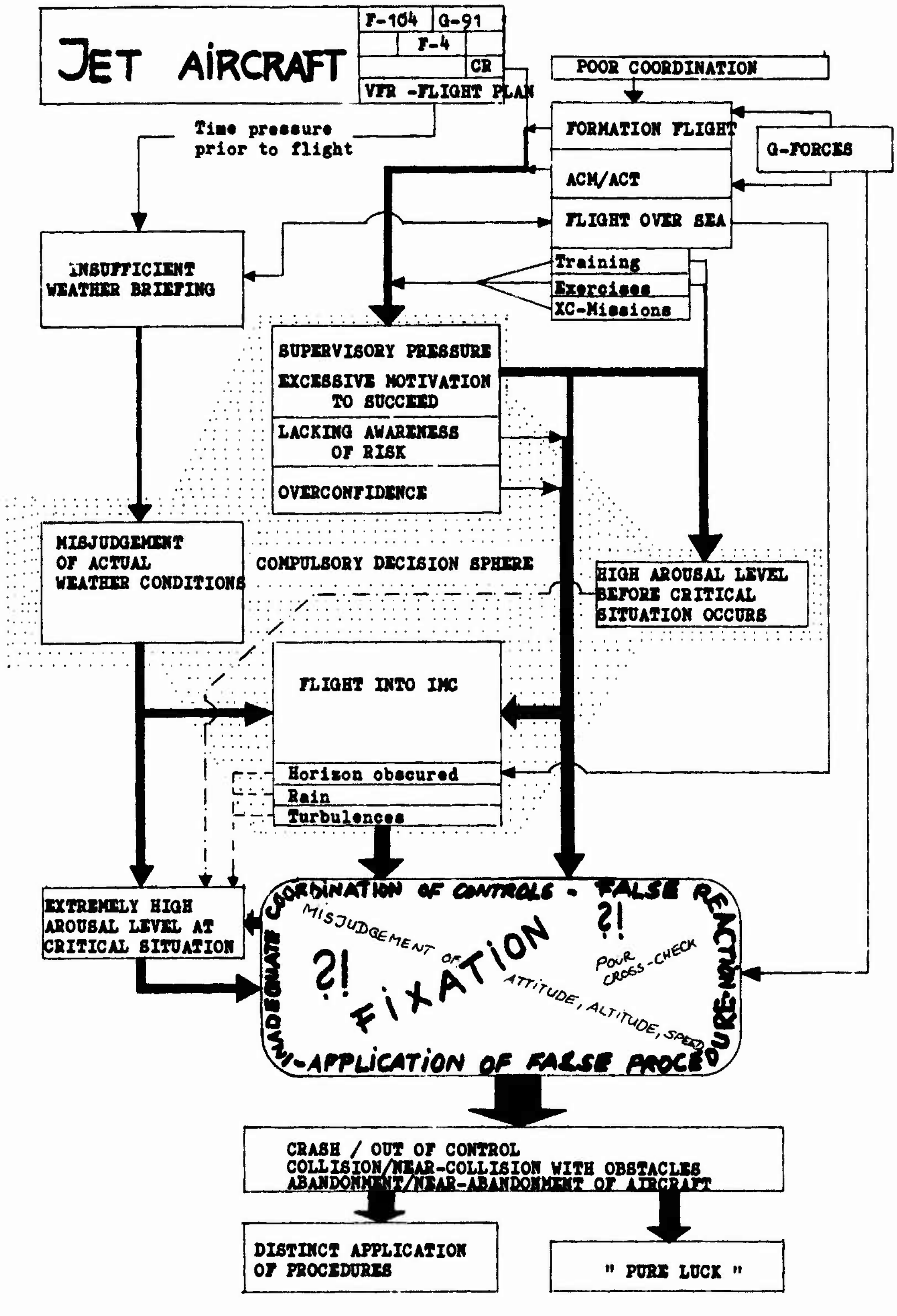



Figure 19. Human factor in spatial disorientation.
( Results of a study )

## 7. AIRCREW SELECTION

Effective aircrew selection is one of the most important factors in saving costs and getting the right people for the job. The training capabilities of an individual is a function of his physical and psychological predisposition. The modern clinical methods of checking the physical status of flight candidates are generally quite sufficient to predict the aptitude to become a pilot. But considerations should be made to check the candidates in respect to their possible future assignment. Organized physiological criteria have to be established and additional tests like centrifuge runs in order to check the individual G-tolerances have to be performed to preselect the candidates before they start pilot training.

On the psychological side, it is much more complicated to establish criteria which could produce the least loss rate. Carefully made studies revealed, that the following criteria essentially determine man's ability to fly:

(1) The ability to screen consciousness against mission-irrelevant external and internal cues and to maintain a high level of attention over a longer period of time.

(2) The ability to devote attention to multiple subjects and events.

(3) Above average capabilities in the area of perceptive and mental information-processing and in psychomotor coordination and precision.

(4) Good short-term and long-term memory.

(5) The ability to tolerate stress of any kind, without reacting with emotional or somatic symptoms or loss of performance.

(6) The ability to react properly on rapidly changing situations as in emergencies, not only in a procedural manner, but in a flexible course of action.

(7) A certain degree of aggressiveness and proper risk-cognizance.

(8) High performance- and flight motivation united with strong self-confidence into the inhabited individual performance capacity.

To meet these criteria, the selectional process should include:

(a) A psychological preselection.

(b) A general psychological examination, using modern test equipment (analyzer-systems).

(c) A general military training (Officer's School, Academy, etc.).

(d) A screening, including academics and actual flying (Solo), monitored by military superiors and aviation psychologists.

The selectional system presently used by the German Federal Armed Forces has a 70 to 30% ratio, i.e. from one hundred candidates thirty will actually start Undergraduate Pilot Training (UPT). Within UPT and advanced pilot training only an additional 5 - 10% are washed out.
Without consequent psychological selection more than 50% would be washed out during the different flight training phases. As pilot training costs increase, vain investments will considerably increase the budgetary burden.

Selection of the right man for the aviator's job, teaching him how to fly and then how to use the airplane as a weapons-platform is well monitored and evaluated. But then, after pilots get combat-ready, the efforts of monitoring and controlling those previously checked qualities becomes negligent, or self-induced system constraints lead to deficiencies with the result of an extraordinary increase in accidents or incidents.
Quite often only <u>one</u> variable in the complicated loop has to be changed to do away with the problem. It is therefore important to continuously adapt the man-machine / machine-man loops and control the results under operational conditions to optimize performance and reliability.

ADAPTATION MAN - MACHINE
(suitable for requirements)

- o Establishment of physical and psychological standards
- o Selection of adequate candidates
- o Training of selected personnel
- o Organization and management of personnel
- o etc.

ADAPTATION MACHINE - MAN
(anthropological)

- o Cockpit design
- o Design of controls and regulators
- o Installation of computers
- o Development of survival equipment
- o etc.

SYSTEM - CONTROL UNDER
OPERATIONAL CONDITIONS

- o Analyzation of technical and human deficiencies
- o Accident cause investigations
- o Diagnoses of physical and psychological adaptation problems

CORRECTIONS IN THE HUMAN SUBSYSTEM

- o Special training programs
- o Medical and psychological rehabilitation and prevention

CORRECTIONS IN THE TECHNICAL SUBSYSTEM

- o Modification and information about critical technical system-components

OPTIMIZATION OF PERFORMANCE AND RELIABILITY

Figure 20. Adaptation components in man-machine systems (after K. Gerbert)

8. CONCLUSION

An inherent hazardous accident potential can be found in the structures of pilots, media, machines, and missions. "Pilot Error" or "Human Factor" are commonly used categories but are surely rude simplifications because they are mostly cross-coupled with conditions which are hardly to be manipulated by the pilot in his cockpit. They sometimes even exceed his adaptation capabilities. In our recent study made with 1460 pilots we have asked for all possible factors and conditions leading not only to accidents but to "simple" critical situations, too. The big advantage of the study was in the absolute anonymity assured to the pilots. Figure 21 shows the most frequent conditions found in the evaluated questionnaires combined with a possible realistic mission-demand profile.

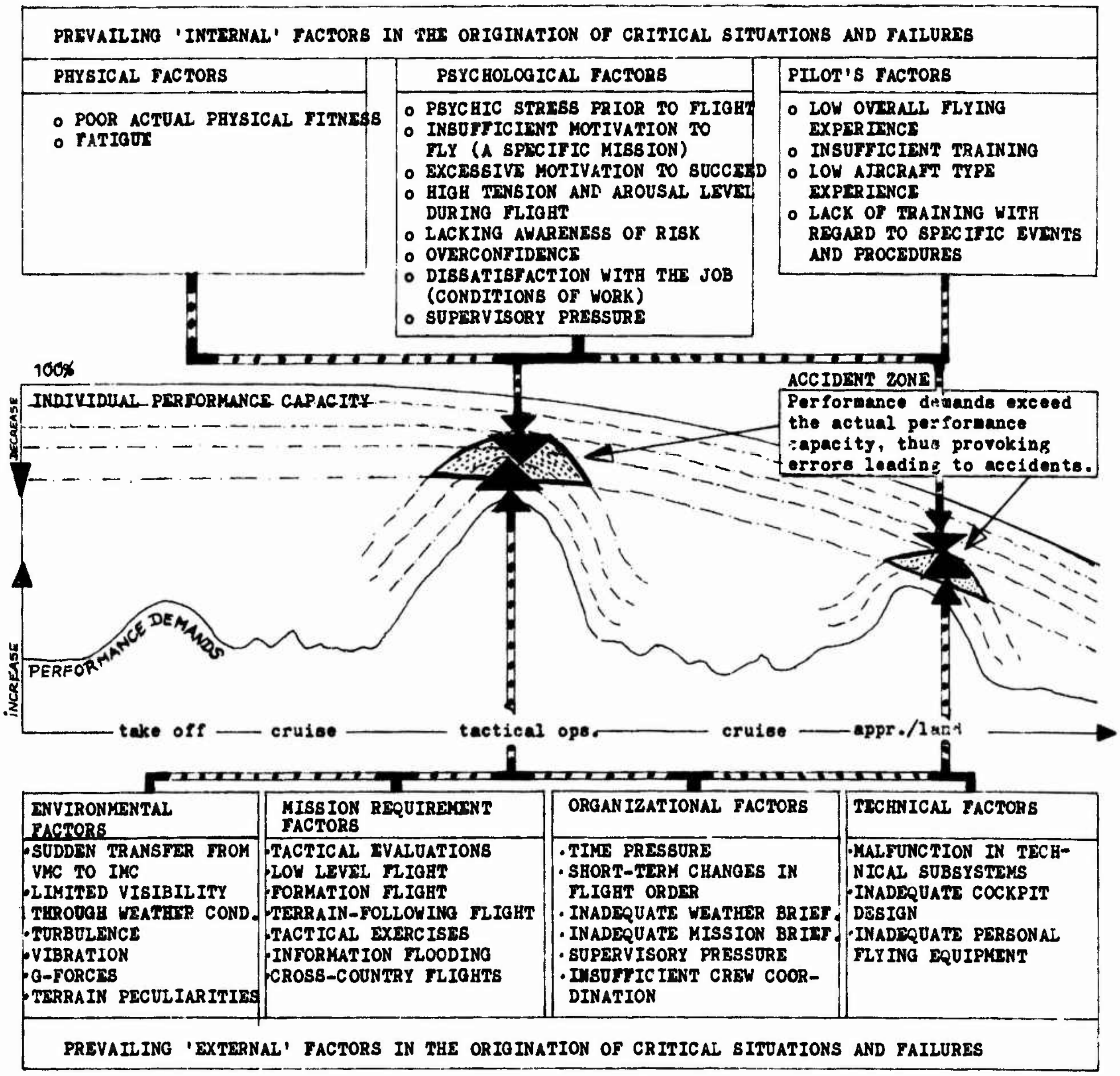



Figure 21. Accident-Zone Model.

As evident, the safety margin increases with decreasing intra-personal negative factors impairing flying performance and moreover with decreasing marginal external conditions.
The safety margin decreases as the sum of internal and external marginal conditions increases.
A simple formula to increase flight safety in aviation would be: Increasing, respectively maintaining human performance capacity plus reducing demands and stresses.

The application of this formula in the field of military aviation naturally has limitations depending on mission requirements, complexity of weapon systems and unmanageable environmental factors. To decrease absolute accident rates, cause and condition variables should be carefully monitored in an effort to modify critical variables, thus preventing the accumulation of unfavourable conditions and diminishing destructive combinations and effects. This is particularly true for the physical and psychological conditions as well as for organizational and proficiency conditions. Avoidable, changeable or at least diminishable variables are:

(1) Educational- and training state of flight crews.
The responsible superiors should know about the strong and weak points of their assigned pilots or crews and relate their actual performance capacity to the requirements of the proposed mission. In addition the prevailing environmental conditions have to be taken into consideration.
Crews should be informed and trained to cope with specific danger areas of certain missions, and decision alternatives in connection with a possible change of external conditions (i.e. weather) should be planned.
Flying safety cannot be emphasized if at the same time the pilot is forced into mission accomplishment when prestigeous exercises are to be performed.
Responsible commanders should have means to continuously and objectively assess the flying proficiencies and capabilities of their assigned crews.
Grading systems, not only for students but for operational combat-ready pilots, have to be established to prevent: "Flight ordera beyond pilot's capability".
The training programs are to be checked if crews are sufficiently prepared for the demands posed on them in operational flight not only concerning special events but also possible demands which could result from abrupt changing environmental conditions. This is particularly important during low level flying under marginal weather conditions.

(2) Lack of superintendence.
Inadequate flight preparation is one of the major factors producing excessively high arousal levels with subsequent significantly higher chances of decision-making errora which then could be the first link in the chain of events leading to incidents or accidents.
Furthermore, the time pressure often induced by superior commands or commanders in connection with a certain supervisory pressure has to be avoided if flight safety is paramount to mission accomplishment in a peacetime-training environment.
All this can only be assured if the right man is placed in the right position.
Special criteria and courses have to be established, covering all areas concerned in the man-mission-medium-machine-management-complex, especially for personnel responsible for the actual crew-mission coupling.

(3) Relevant conservation of internal conditionc.
Degradations in physical and psychological performance capabilities are typical error-provoking conditions. Personal conflicta and problems, anger and dissatisfaction with the job are important side conditione which have to be eliminated by proper leadership technique as they directly relate to flight safety.

Nevertheless, quite a number of pilots and responsible military leaders when asked about their personal efforts about preventive measures for flight safety stick to the old saying:

"You cannot make an omelette without breaking eggs!"

This is absolutely correct in times of war, but in line with that old saying all possible efforts should be made, not to "drop too many eggs on the way from the refrigerator to the bowl!"
This is particularly true nowadays as inflation makes the prices go up and "good cooks are hard to get."

**REFERENCES**


(1) Gillies, J.A., A Textbook of Aviation Physiology, Pergamon Press, 1965.

(2) Bond, N.A. et al., Aviation Psychology, Aviation and Missile Safety Division, University College, University of Southern California, March 1962.

(3) Gerbert, K., Abriß der Flugpsychologie, German Air Force Institute of Aerospace Medicine, Aviation Psychology Branch, (not published).

(4) Birbaumer, N., Physiologische Psychologie, Springer Verlag 1975.

(5) Murrell, K.F.H., Ergonomie, (Ergonomics-Man in his working environment (1969)), Econ Verlag, 1971.

(6) Roscoe, S.N., Aviation Psychology, The Iowa State University Press, Ames, 1980.

(7) Steinbuch, K., Automat und Mensch, Kybernetische Tatsachen und Hypothesen, Springer Verlag, 1965.

(8) Hassenstein, B.,Biologische Kybernetik, Quelle und Meyer Verlag, Heidelberg, 1967.

(9) Chopping, D.F., Sicherheit in der Luftfahrt, Interavia, Schweiz, Vol 32, 1977, Jan., S. 67-68

(10) Haakoson, N.H., Investigation of Life Change as a Contributing Factor in Aircraft Accidents: A Prospectus, presented at JCAP Meeting, Sept. 78.

(11) LePage, W.A., et al., "A Conceptual Model for the Effects of Operational Str..s", 1976, AGARD-CP-181, p. C9-1.

(12) Franke, H.W., Der Informationsumsatz im Menschen, Deutsches Ärzteblatt, Nr. 27/ 5.7.1969.

(13) Friedrich, J., Zur Begriffsbestimmung und Erfassung der Leistungsfähigkeit aus luftfahrtmedizinischer und-psychologischer Sicht, Zeitschrift für Militärmedizin, 3/78, DDR.

(14) Gerbert, K., et al., Der Faktor Mensch und seine Beziehung zu Umwelt- und anderen Randbedingungen, Studie, General Flugsicherheit in der Bundeswehr, April 1982. (Restricted).

(15) Gerbert, K. and Spohd, G.O., Investigation of Human Factors in Aircraft Accidents and Incidents of the German Air Force, ASMA - Meeting, May 1982, Bal Harbour, Fl. USA.

# PATHOLOGY ASPECTS OF THE HUMAN FACTORS INVESTIGATION

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SUMMARY

This lecture outlines the principles of aviation pathology with particular emphasis on utilising autopsy examination in search of the twin objectives of establishing the cause of the accident or assessing the reason for fatalities occurring; in this mode, forensic pathology is an expression of preventive medicine. Possible causes for the accident are to be found, in the main, through the examination of the flight deck crew; such causes may be pathological, toxicological, physiological or mechanical. Abnormalities are often easy to find; the lecture emphasises that the major difficulty lies in interpretation of the findings. The prevention of fatal accidents is illustrated by the use of pathology in the development of the ejection seat and by a study of light aircraft accidents resulting in fatal head injuries. In accidents involving large aircraft, the importance of establishing a pattern of injuries so as to indicate the type of the accident is enlarged upon. Pathology is regarded as an essential part of the investigation of an aircraft accident but, like any other discipline, it only functions at its best in the context of a 'group system'.

In this lecture, I am going to consider only the wholly fatal accident. The pathologist has a role to play in circumstances of partial survival but, in general, this will be of confirmatory value only, since better evidence will be available from other sources. The situation is different when the only human evidence is to be derived from cadavers. The contribution of the human factors team then rests on purely deductive reasoning; the forensic pathologist's part in accident investigation is as great or greater than it is in the investigation of homicide and his input must be of the same quality - and receive the same consideration from the other investigators.

The pathologist must depend to a very great extent, but not, as we shall see, entirely, on the autopsy. His function in undertaking a post-mortem dissection is far more than ascertaining the cause of death and, in the case of multiple fatalities, more than assisting in the identification process. He should be striving towards twin goals:

(a) to discover the cause of the accident with the ultimate objective that someone will eliminate that cause from future operations. If he cannot do this - and not all accidents can be prevented - he has a second useful line of approach which is

(b) to discover the cause of a fatal accident. This is essentially a matter of disclosing the injuries sustained, correlating these with the safety equipment in use and thus providing the evidence by means of which that equipment may be improved.

These two objectives are not quite the same but both are devoted to saving lives in the future. The first applies this principle on a community basis, the second is devoted to the safety of the individual.

## The cause of the accident

With the major exception of sabotage, which I propose to deal with in my second lecture, the cause of an accident is most likely to be found as the result of autopsy on the pilot or on the flight deck crew. This means to say that, since discovery of the cause is the fundamental reason for the investigation, the autopsy of the flight deck personnel is essential. There can, in my opinion, only exceptionally rarely be valid reasons for not carrying out this investigation.

It is useful, again, to have some indication of objectives and we can divide these into four categories of cause which are potentially discoverable by the pathologist:

(a) Pathological
(b) Toxicological
(c) Physiologioal
(d) Mechanical

### Pathological Causes

I start with this aspect because it is most clearly that which one would expect the pathologist to recognise. Basically, we are seeking disease in the pilot which has affected him to the extent that it has caused an accident[1].

In the ordinary run of forensic work, the discovery of disease is not difficult and its interpretation is relatively simple. But once one introduces the variable of trauma, the skill required of the pathologist becomes greater .

Firstly, there are purely technical difficulties. The diseased tissue may be destroyed or the appearances may be modified by trauma - as an example, a naturally occurring cerebral haemorrhage may be 'masked' by injury to the head. What is less commonly appreciated is that trauma may mimic disease and disease may mimic trauma. Unfortunately, this is particularly true of coronary disease where the disruptive effects of an acute intramural haemorrhage may be indistinguishable from those due to injury to the heart; similarly, the pulmonary appearances of acute left ventricular failure are very similar to those of ulmonary concussion. Moreover, a disease process may be interrupted by trauma. It is, for example, easy to diagnose a myocardial infarction in normal sudden death. But in the aviation situation, all that needed to precipitate an accident is an anginal pain; there is then no time for ·ardial changes to occur before death results from trauma.

Secondly, there are difficulties of interpretation. Whenever disease is discovered we must ; se for ourselves three alternatives: was it

(a) Causative
(b) Contributory
(c) Merely incidental to the resulting accident?

This difficulty is especially well illustrated by the condition of coronary atheroma which occurs significantly in up to one quarter of those of aircrew age[2] and which is often responsible for sudden death without any evidence of acute exacerbation. The first, and major, lesson to be learned is that discovered pathology can only be properly interpreted in the light of the circumstantial evidence; and the circumstantial evidence will include the incidence of the condition in the population at risk.

Taking this rule one stage further, we can appreciate that the likelihood of a disease actually causing an accident is a product of the severity of the disease and the stressfulness of the circumstances; minor disease, which might go unnoticed in a cargo flight, may be lethal to a fighter pilot. I regard this as sufficiently important to recommend that, in normal peace time conditions, combat aircrew should be positively discouraged from training flying while suffering from any disability. By contrast, the presence of some disease may be acceptable in certain circumstances particularly when, as with coronary atheroma, the elimination of all disease also severely reduces experience· an adequate double crewing routine is a far greater safeguard against a disease provoked airline disaster than is any increase in the sophistication of electrocardiographic techniques.

Also to be considered under this heading are those diseases which leave no trace at autopsy. The most important of these is epilepsy, to which I shall return, but the most complex to evaluate are the simple psychiatric disorders. The confident attribution of a causative role to, say, anxiety is almost impossible but the possibility leads us to a second lesson which is that the forensic expert must be in possession of a medical history of a fatality before he can adequately interpret his findings.

## Toxicological Causes

Toxicological causes of accidents may be endogenous or exogenous. In either event, the same cautious approach must be taken as has been indicated with pathology - the mere identification of a toxic substance or product is insufficient; what matters is the interpretation of the laboratory findings. Moreover, we must be assured of the adequacy of our technique; a laboratory method which is designed, say, to identify a suicidal level of a toxic substance in a fresh specimen may be quite unsatisfactory for determining levels sufficient to cause an accident in a severely traumatised or putrified body.

Endogenous causes. Here I would include alcohol and drugs. In brief, alcohol appears to be a problem only in private, general aviation where something of the order of 16 per cent of fatal accidents are alcohol associated[3]; the influence of the 'hangover' on military aviation accidents does not, however, seem to have been fully evaluated. The most important investigative problem lies in the interpretation of blood levels derived from post-mortem specimens but I will return to this under the heading of medico legal aspects.

Drugs also seem to be concerned only with general aviation accidents and post major difficulties for the investigator. It is time consuming and costly to examine for drugs at therapeutic levels in a purely random manner. Selection is necessary and the services of a specialised laboratory are essential. The problems of interpretation then become maximised. For example, who is to say that a pilot on recognised doses of an anti-nauseant is any more or less dangerous than one who is suffering from air sickness? The presence of drugs may indicate a significant underlying disease but this evidence may be of both a positive and negative nature. Thus, the finding of phenobarbitone could suggest that a casualty was an epileptic; but the absence of drugs in a man who, from the circumstantial evidence, was thought to be an epileptic might be very significant evidence that the accident was due to the disease[4].

Exogenous Causes. While fumes of several sorts could, theoretically, affect aviators, I will discuss here only carbon monoxide because this gas poses a practical problem and illustrates well the recurring dilemmas of interpretation.

Carbon monoxide intoxication should be sought in every fatal vehicular accident not only to exclude frank pilot or driver incapacitation but also because it may indicate the presence of an engine defect. It cannot, however, be stressed too strongly that the commonest cause for a raised carboxyhaemoglobin in a fatality from a vehicular accident is survival in the presence of fire; it is, therefore, essential that the toxicological result is interpreted only in conjunction with the post mortem findings related to the active inhalation of soot or flame and, unfortunately, these do not always show perfect correlation[5]. Moreover, the investigation must take into account the 'normal' levels of carboxyhaemoglobin which may rise to 10 per cent in heavy smokers; the coincident estimation of nicotine levels may help to identify such instances.

Carboxyhaemoglobin is relatively stable in post mortem tissues but the quality of the specimen obtained from aircraft fatalities may be very poor; this emphasises again the importance of laboratory technique. Thus, the interpretation of carboxyhaemoglobin levels is fraught with difficulty and, while occasional cases of very great importance have been reported (see, for example, Stevens[4] at p. 31), intoxication by carbon monoxide is generally of concern only in aircraft powered by reciprocating engines. I have found this aspect of toxicology to be of greatest use in major disasters in providing an indication of the nature of the catastrophe (see below).

Physiological Causes

Many of the physiological hazards of aviation leave no mark when they precipitate an accident and this includes the important general fields of stress, disorientation and fatigue. Positive radial acceleration is not demonstrable at autopsy but negative 'g' leaves very clear evidence in the form of subconjunctival haemorrhages when it has been severe; this is particulrly apparent in 'tumbling' episodes during parachuting.

I have been disappointed in attempting to diagnose rapid decompression as a separate entity. Any pulmonary effects noted are, essentially, those of hypoxia or terminal impact; rupture of the eardrums is a feature of uncontrolled descent rather than physiological ascent; much has been written about the association of pulmonary fat embolism with rapid decompression[6] but later experience suggests that it is difficult, if not impossible, to distinguish this from embolism due to associated turbulence. There is no reason to suppose that the well documented findings in post-descent shock can be extrapolated to the acute condition.

Hypoxia undoubtedly does leave post mortem evidence in the form of pulmonary congestion and oedema but very similar changes can be attributed to deceleration injury. As a consequence, it is extremely difficult to say that a severe crash of, say, a fighter aircraft was due to an anoxic episode; the pulmonary changes may, however, be of great value in distinguishing multiple casualties some of whom have died from injury and others from hypoxia following a catastrophe at altitude.

Prolonged attempts have been made to relate realistically the post mortem biochemistry of the body to its ante mortem physiological state. Despite some promising indications, most workers would now agree that the methods are impracticable.

Mechanical Causes

Apart from sabotage, which is discussed elsewhere, the pathologist's evidence as to a mechanical cause of an accident is likely to be only confirmatory of the engineering opinion - thus, near disintegrative destruction of bodies is likely in the event of major control failure as in the loss of a tail assembly.

Occasionally, the pathological evidence may negative an apparent mechanical explanation for a disaster. Thus, on one occasion, what seemed to be a primary wing failure was shown to be, in fact, secondary to abnormal stressing due to a passenger collapsing while seated in the co-pilot's seat. Even more rarely, the pathological findings may positively direct the engineers in their investigation. I recollect a navigational training aircraft breaking up in the air. The significant pathology was that the pilot and two pupil navigators showed identical injuries attributable to a fall from a height; the staff navigator and signaller sustained severe impact injuries on the flight deck. The conclusion was inescapable that, at the time of the breakup, the pilot had been in the fuselage with the pupils and, from there, it was not difficult to suggest that the automatic pilot had failed - in fact, a correct deduction. The illustrative importance of this case, however, lies mainly in the fact that the medico legal investigation had been considered complete when the pilot was adjudged to have died from multiple injuries. There can be few better examples of the difference between such routine work and true investigative pathology.

Synergism

Before concluding this section, a mention should be made of the concept of synergism in accident causation. This implies that, although no single factor can be regarded as sufficient to be causative, the combination of a number of such findings may provide the answer to an otherwise 'cause unexplained' fatal accident. Thus, moderate

coronary disease may appear to be an incidental finding on its own; add to this a stressful situation and it may become contributory; add a moderate degree of hypoxia and the combination may be causative.

Such analyses need to be made with even greater care than has been described but, once completed, the result of the exercise may be very persuasive.

## The nature of the accident

The pathologist examining a major disaster has the advantage that he can form an impression of the pattern of injuries among a large number of fatalities.

The pattern may be uniform throughout the cadavers and it is so in the majority of 'ordinary' accidents. It may, however, be discordant in which case a strong suspicion that one is dealing with an unusual incident should be aroused. At the same time, experience shows that patterns tend to reproduce themselves in different accidents; if the nature of the original is known, it is reasonable to suppose that an accident producing a similar pattern is of similar type. Conversely, if the nature of an accident is presupposed, an ill-fitting pattern may provoke second thoughts[7]. A very unusual accident occurring some 2 kilometres from an airport was strongly suspected of being due to military action which would have resulted in a crash pattern of injuries; in the analysis, the pattern was found to correspond precisely with a known undershoot incident investigated some months previously and subsequent investigations confirmed this interpretation.

The pattern may relate to generalised injuries indicating the severe forces involved; lower limb tibial fractures strongly suggest horizontal forces whereas femoral fractures are associated with a severe vertical component of force, this often being mirrored in the spinal injuries; products of combustion in the air passages prove that the crash forces were survivable and, complementary to this, a toxicological pattern may be established. Indeed, the concept of the use of patterns of injury can be extended into the fields of safety engineering and will be discussed in the next section. Moreover, only in this way can one arrive at a reasoned appraisal of the injuries which are likely to be sustained by survivors from similar accidents of slightly lesser intensity. The examination of all fatalities from a major accident may seem an unnecessary task; I do not recall a time which I did not feel it had served a useful purpose.

## The Prevention of Fatal Accidents

The patholgist's involvement in safety engineering is wide despite the fact that his evidence must be somewhat negative since, by definition, he is concerned in cases where there has been a failure of safety equipment.

If equipment has been provided, the autopsy examination should be devoted to establishing whether it was properly used; whether it was inadequate or could be usefully modified; and whether its use affected the fatal outcome. This last is important because all safety equipment design is a matter of compromise and those conditions in which it actually has an adverse effect must be carefully identified. In the event that equipment was not available, an opinion will be sought as to whether its provision would have led to survival in the instant case or in similar but not identical cases in the future.

Some of these points were well illustrated in the era of development of the ejection seat during which fatalities occurred as a result of poor positioning at the time of firing, entry to the airstream, striking the aircraft, seat strike, drogue failure, environmental factors, parachute opening shock and deceleration injuries on landing. A careful autopsy with equally careful correlation of the medical and engineering findings when the equipment was also available for examination provided important data for modification design and also for reconstruction of those cases in which the equipment was lost[8].

An example of how pathology can stimulate regulatory policy was provided by a study of deaths in general aviation accidents[9]. As a result of integrated pathological/engineering investigation, it was established in the United Kingdom that 40 per cent of those killed in light aircraft would have survived had they been equipped with adequate shoulder harness restraint. Further evidence was adduced that effective head protection should include a face-guard. Similar findings were being reported world wide and most countries have now introduced restraint regulations for front seat occupants in light aircraft.

The role of pathology in commercial avaiation safety must also be considered. Essentially, the highlighting of dangerous features depends, again, on establishing a pattern of injuries and relating this to the passenger environment. A major example of this type of work involved a relatively survivable accident in which, in fact, the great majority of passengers died from burning or asphyxia; this was shown to be due to their immobility following fracture of the lower legs associated with the seat design[10].

## The Pathological Investigation

It is apparent that the full potential of the pathological investigation cannot be

realised if the pathologist works in isolation. Aviation pathology is, above all, an exercise in cooperation[11].

I believe that the pathologist, while taking all specialist advice which is available, should personally verify most of the circumstantial evidence on which so much of his interpretations will depend. The following are important:

(a) a visit to the scene
(b) an examination of relevent safety equipment and clothing
(c) taking a full part in any identification procedures
(d) performance of the autopsy
(e) supervision of ancillary laboratory work.

All this requires the help and understanding of others. In particular, the investigator in charge must be convinced of the usefulness of medical participation. Not only must his guidance be sought but he must be immediately advised of any unexpected developments; a daily meeting is advised in all major investigations. Secondly, and of overriding importance, there is the need to have the cooperation of the police and legal authorities; this will be discussed more fully in the second lecture. Finally, there must be full integration with professional colleagues of all disciplines. It is imperative to a good investigation that no one cadre of workers attempts to 'steal the limelight' or to appear more important than the others. The full benefits of accident investigation stem from the unstinting application of the 'Group System'.

REFERENCES

1. Mason, J.K. 'Previous disease in aircrew killed in flying accidents', Aviat Space Environ Med 48:1977, 944-8

2. Underwood Ground, K.E. 'Prevalence of coronary atherosclerosis in healthy United Kingdom aviators', Aviat Space Environ Med 52:1981, 696-701

3. Ryan, L.C. & Mohler, S.R. 'Current role of alcohol as a factor in civil aircraft accidents', Aviat Space Environ Med 50:1979, 275-9

4. Stevens, P.J. 'Fatal Civil Aircraft Accidents', Bristol: J. Wright & Sons, 1970, p.107

5. Blackmore, D.J. 'The determination of carboxyhaemoglobin and its importance in aviation accidents', in 'Aerospace Pathology' eds. J.K.Mason & W.J. Reals, Chicago: College of American Pathologists Foundation, 1973, Chap. 20

6. Armstrong, J.A. et al. 'Interpretation of injuries in the Comet aircraft disasters' Lancet 1: 1955, 1135-44

7. Mason, J.K. 'Passenger tie-down failure: Injuries and accident reconstruction', Aerospace Med 41:1970, 781-5

8. Mason, J.K. 'Transportation accidents', in 'Gradwohl's Legal Medicine' 3rd ed., eds. F.E. Camps, A.E. Robson & B.G.B. Lucas, Bristol: J. Wright & Sons, 1976, Chap. 21

9. Cullen, S.A. 'Death in general aviation accidents and its prevention', in 'Aersopace Pathology' eds. J.K. Mason & W.J. Reals, Chicago: College of American Pathologists Foundation, 1973, Chap. 12

10. Board of Trade 'Report of the Public Inquiry into the causes and circumstances of the accident to Canadair C4 G-ALHG, 4th June 1967', 1968, CAP 302, London: HMSO.

11. Mason, J.K. 'Aircraft accident pathology: A study in co-operation', Milit Med 130:1965, 578-85

# THE ENGINEERING INVESTIGATION OF AIRCRAFT ACCIDENTS

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## 1. SUMMARY

Most aircraft accidents occur with little or no warning, and an atmosphere of confusion can result in trying to find the cause unless adequate plans, trained personnel, and special facilities are available. Most organizations use a pre-accident plan which lists the factors needed to prepare for and expedite an accident investigation. Topics covered in this paper include the organization and plan for an investigation, procedures used at the scene of the accident, engineering aspects covered in the main investigation, use of special analytical techniques and simulation tools, and use of flight recorder data. Examples of investigations are used to illustrate the processes used.

## 2. INTRODUCTION

Although we have been able to improve our understanding of the causes of aircraft accidents, we are continually challenged to understand how the human/machine combination can interact adversely, causing catastrophic consequences. In spite of programs stressing mishap prevention, accidents will occur; most accidents result from human inadequacies. If the true causes of past accidents can be well established, more effective action can be taken to prevent future accidents.

The purpose of this lecture is to discuss several of the engineering methods used in military aircraft accident investigations with a view toward obtaining a better understanding of human failure aspects.

The scope of the presentation is limited to the following: (1) organization and planning of an investigation, (2) procedures used at the accident scene, (3) on-site preliminary investigation procedures, (4) areas to be covered in the detailed investigation, (5) human factors considerations, and (6) use of analytical and simulation techniques. Several aircraft accident case histories are included to illustrate the techniques being used.

## 3. DISCUSSION

Accident investigations methods used by the U.S. military services, whether Air Force, Army, Navy or Marines, are basically similar. For convenience, the procedures used by the Navy (Ref. 1) will be followed.

A satisfactory investigation should have several essential features including (1) promptness in getting to the scene of the accident before evidence is disturbed; (2) complete and thorough examination of all evidence; (3) layout of logical, straightforward procedures specifically oriented to the accident under investigation; and (4) accuracy of material in note taking.

### 3.1 Organization of an Investigation

An aircraft accident investigation is a specialized task in which every factor, remote or small, must be studied in an organized plan to reconstruct what actually occurred. There are several general principles to consider and actions to take in the organization plan for each accident. For example,

1. Apply the basic principle that the only limits to the amount of effort justified to prevent the recurrence of a mishap are those established by time, cost, and performance bounds peculiar to each particular program.

2. Have available and execute an effective pre-accident plan.

3. Arrive at the scene of an accident before evidence is disturbed, safeguard the area and prevent unnecessary handling or moving of wreckage, and then proceed as follows:

   a. Determine the best investigative procedure and board composition suitable to the mishap.

   b. List witnesses for subsequent interviewing.

   c. Obtain complete photographic coverage (including sketches, plots, etc.) of wreckage and related area.

   d. Investigate and follow up clues while they are fresh.

   e. Arrange for and secure any special or technical assistance required at the accident scene.

4. Examine all evidence in detail:

   a. Do not take anything for granted.

   b. Question all persons having any knowledge of the accident.

   c. Preserve wreckage and evidence at the accident scene until the initial phase of the investigation is completed.

d. Follow every lead and source of information possible to the maximum extent of usefulness.

5. Conduct an organized, planned, and controlled investigative effort:

   a. Follow each phase of the investigation in a systematic manner.

   b. Avoid reaching premature conclusions or leaving any investigation area uncovered.

   c. Look for interrelated or overlapping events or occurrences.

6. Be accurate and complete:

   a. Take accurate and extensive notes on all facts during investigation; develop these notes as applicable.

   b. Verify all witness statements.

   c. Emphasize the use of factual evidence supplemented by theories which can be well substantiated.

   d. Develop theories and relate to facts. Then reconstruct events.

   e. Document and present findings in a concise manner to facilitate evaluation and drawing conclusions.

6. Be objective in evolving conclusions and recommendations.

7. Delineate the type of accident:

   a. No survivors; extreme disintegration of aircraft (hole-in-the-ground type).

   b. Survivors.

   c. No survivors or wreckage available.

   d. Minor accidents.

For the "nonsurvivor" accident, the events preceding the crash must be reconstructed from several sources: (1) all witnesses to the accident should be located and interviewed; (2) all pieces of wreckage must be recovered and inspected by qualified personnel and placed to form the outline of the aircraft for systematic analyses; (3) an accurate wreckage distribution pattern, estimate of flight path, and impact orientation must be determined; (4) all available records, including pilots log, aircraft and engine logs, maintenance reports, weight and balance, etc., should be checked.

For the "survivor" accident, there is a vital witness available to help clarify the series of events leading to the accident. Since the aircraft may have been totally destroyed, sources similar to those used on the nonsurvivor accident must be pursued.

When there are no survivors or wreckage, the accident investigation is more difficult. In this case it is mandatory to carry out the following steps: (1) obtain and review all witness statements; (2) interview all personnel concerned with the flight operation of the aircraft; (3) study all records, logs, personnel histories of the crew, flight plans, navigation and weather data; and (4) examine all operational and maintenance procedures.

3.2 Procedures at the Scene of the Accident

It is necessary to have a good plan of action to follow at the scene of the accident to avoid waste of time and general confusion. The following general procedures should be used at the accident scene.

3.2.1 Officer in charge. Surviving crew members (if physically able) or the first military personnel arriving at the accident scene can take charge until a senior board member appears who should coordinate activities of rescue personnel, investigators, medical personnel, salvage crew, and civil authorities.

3.2.2 Safety considerations. The officer in charge should ensure that all occupants of the aircraft are removed from the wreckage as expeditiously and safely as possible. Immediate steps must be taken to prevent injury to personnel from fire, fuel explosion, armament cook-off, ejection seat and canopy charge detonation, and other explosions.

3.3 Preliminary Investigation of Accident

The purpose of the preliminary investigation is to familiarize the accident board with the general aspects of the accident and salient details of the wreckage.

3.3.1 Wreckage analysis. The physical evidence at the accident scene should be examined to determine how the aircraft contacted the ground. A detailed inspection of all of the wreckage should be made to determine causal factors, including material failure and engines and system malfunctions. The examination of the surrounding terrain, objects struck by the aircraft, witness statements, and other evidence will indicate flight path prior to impact. The approximate attitude of the aircraft at the time of impact can be determined by the distribution of the wreckage and the aircraft damage.

3.3.2 Wreckage pattern. The distribution of the wreckage can be very helpful in determining aircraft behavior in the final phases of flight. Most wreckage patterns will be similar to the following:

1. Dives into the ground are characterized by wreckage confined to a circular area around a ground crater. The speed at impact can be crudely assessed by the depth of the crater; jet aircraft will penetrate 30 to 40 ft.

2. Spins are easily identified by a small compact pattern with indications of rotation found on the ground. The inside spin wing will sustain greater damage with the outside (spin) wing showing less deformation as it will usually be thrown forward. The fuselage will be broken in several places, and the empennage will be thrown forward in the direction of spin rotation.

3. Low (flat) attitude flight is characterized by a long narrow distribution pattern. High-speed impact will usually result in the engine and other heavy parts progressing farther along the ground than the aerodynamic structure. A stalled-in approach may show an initial ground impact point (caused by the tail contacting the ground) and then a deeper gouge of the main wreckage. The stopping distance can be accurately measured to provide important clues to estimate aircraft speed and corresponding flight path angle.

4. Loss of control in cruise flight will generally result in a spiral with a nose-down attitude and a large bank angle. The collapse of one wing with corresponding ground scars followed by cartwheeling is typical of spiral out-of-control accidents.

3.3.3 Wreckage recovery. The problem of wreckage recovery can vary greatly, depending upon whether the accident occurred on land or water. On land, after wreckage distribution diagrams and photographs have been made, each piece of wreckage must be catalogued, noting whether any parts may have separated from the aircraft before the crash. When aircraft wreckage is under water, care must be taken to categorize damage inflicted during recovery operations. Parts suspected of failure should be tagged to identify their relationship to the accident. In cases of engine failure, it is necessary to obtain fuel and oil specimens for laboratory analysis of foreign matter.

3.3.4 Fire damage. If fire occurred prior to impact, the origin of the fire and how it was fed must be determined. An in-flight fire can be identified by the direction of molten metal flow and smoke patterns that leave clear spaces on the downstream side of rivet heads and skin splices. Ground fires leave a smoke pattern which is sporadic. Crumpled portions of the aircraft can be opened to inspect inner folds which may still retain clean metal or paint.

### 3.4 Main Investigation

This phase of the investigation will provide the bulk of the physical evidence to be used in the analysis. For example, detailed examinations should be made to determine if structural failure occurred in flight. This can be assessed by examining material for overstress and by the detailed wreckage trail. Recent advances in the science of nondestructive testing make available, through existing governmental agencies and private organizations, many laboratory facilities for use in examining parts suspected of failure. Methods and equipment have been developed for identifying failures and deficiencies in areas such as:

1. Structural overstress, flaws, and cracks — detected by the magnetic particle, dye penetrant, eddy current, ultrasonic, and X-ray processes.

2. Electromagnetic and microwave hazards and deficiencies in radioactive isotopes, linear accelerators, and nuclear reactors — detected by radiographic inspections and radiological devices.

3. Material quality and quantity — detected by electron microscope, electron microprobe analyzer, X-ray defraction, spectroscope, infrared, etc.

4. Thermal overloads, inadequate welds, and incomplete bonds — detected by infrared-radiometric microscope.

5. Mixture quality and quantity — detected by gas chromatography and chemical analysis.

6. Physiological aspects — detected through biological and medical techniques and other tools such as infrared absorptiometry, radioactive assay, mass spectrometry, chromatography, ultrafluorescent measurements, cytology, etc.

The importance of other factors such as aircraft configuration, airframe and powerplant failures, and system failures is discussed next.

3.4.1 Aircraft configuration. Knowledge of the aircraft configuration at impact can help identify causes of the accident. The position of flaps, leading edge slats, speed brakes, wing spread locks, and landing gear can indicate the degree of control available before impact.

3.4.2 Airframe failures. Components of the aircraft in relative order of frequency of failure include: wings, tail surfaces, control surfaces, fuselage, landing gear, and trim tabs. Reconstruction of the entire airframe structure may be necessary to determine the sequence of failure. Good reconstruction can reveal the manner in which parts struck each other during breakup. Position of control surfaces at impact can help evaluate stresses imposed on the structure as well as to identify attempted recovery techniques being employed. The cockpit should be checked for evidence of fire, smoke, or electrical arcing, and attempted crew ejection. The position of switches and instrument readings can be correlated with known or planned flight conditions.

3.4.3 Powerplant failure. Since powerplant failures are a frequent cause of accidents, a thorough examination of the engine and its associated components must be made even if only to provide a non-causal factor. Engine failures caused by internal malfunction are relatively easy for competent personnel to

recognize. It is important to determine as accurately as possible the amount of power (thrust) being produced at impact since this could affect flight path control of the aircraft prior to the crash.

### 3.5 Human Factors Considerations

The human element is present in almost every stage of equipment development from its design stage to its operational stage. Thus, the possibility of accident due to human failure is almost always present. Most accidents result from human inadequacies, not material failures or "acts of God." These inadequacies are not always associated with the person immediately involved in the accident, but may be traced to early development stages of the system in question. Human cause factors may be physical, physiological, or psychological, or a combination of these factors.

3.5.1 History of individuals involved. A complete history of the person or persons involved will be useful to determine possible human factors which may have a bearing on the accident. A check on the individual should cover training and proficiency, any recent illness, indisposition, and nonemployment activities. It should determine the amount of duty or rest, mental attitude, freedom from worries or fears, and previous accident record. For example, in a stall accident of a military transport, it was disclosed that the pilot had performed poorly in stall recognition during proficiency checks.

3.5.2 Physical, physiological and psychological limitations. A human can be considered as a designed piece of equipment with limiting capabilities which may be defined and measured in a manner similar to those of a machine. Human limitations involve three basically interrelated components: a physical structure, a biochemical medium, and a psychological system.

A human is first a mechanical structure and, therefore, possesses certain physical limitations including the ability to reach only so far and lift so much. Human sensory systems have definite limitations, and violations lead to inadequate information and improper resolution of the situation. Every human reaction involves a perception and a response separated by some form of decision. Difficulties and accidents will result from any requirement which demands abnormal use of a person's senses, quick decision and action on too much or too little information, or responses which cannot be executed rapidly enough. The relations between instrument displays, ambient lighting conditions, accessibility of control, and ready identification of both instruments and controls are all an integral part of the human engineer's accident prevention efforts.

Humans also have physiological limitations which are based on biochemical properties. A human's structural operation and its sensory systems are directly related to how well its biochemical medium is maintained. Here again are definite requirements which cannot be violated without inefficient operation of the whole system. Reduced effectiveness is particularly dangerous because it makes the person susceptible to errors, but merely reduced effectiveness is less noticeable and less possible to evaluate than acute ineffectiveness. Fatigue is another type of disruption, which results from changes in the body's biochemical balances caused by an accumulation of toxic wastes. When the body is tired, efficiency is markedly decreased, probability of error is increased, and perception of errors committed is less acute. Fatigue is produced by both long hours of labor and irregular hours. Human bodies adapt to physiological cycles of work and rest. The disruption of these cycles contributes to fatigue and inefficiency.

The human is also a physiological being with psychological limitations. Aptitudes, desires, feelings, and abstract motivations provide additional limiting or distracting variables to be considered in ensuring efficient operations. People are emotional; an eager, well-motivated person undistracted by personal problems or tensions, other things being equal, can consistently outperform a distracted or poorly motivated person. When emotional problems are present, the person's mistakes generally involve minor omissions or acts which lead to inefficiency, but they may possibly involve major errors. In investigating accidents involving personnel in critical work situations, the investigator should determine whether these personnel have been routinely evaluated by specialized personnel to ensure avoidance of emotional difficulties which may have contributed to the accident.

3.5.3 Judgment, technique, and proficiency. Questionable judgment, poor technique, or lack of proficiency, when given as an accident cause, often covers a multitude of errors. A pilot or crew member may have demonstrated by years of service and thousands of flying hours that his judgment was inherently good. What were the influences that brought about an error in judgment? Determining the reasons for lack of proficiency may involve deficiencies in equipment and command interest, in addition to individual effort. All influences on human action must be considered and recorded in the accident report in order to realistically evaluate the accident.

### 3.6 Use of Analytical and Simulation Techniques

In many accident investigations, the flight path of the aircraft prior to the crash must be known to determine whether excessive loads could have developed from high airspeed and/or large accelerations. A sister aircraft sometimes is used to simulate the time history of the accident aircraft; however, this method has limitations due to the hazards in approaching the high speeds, extreme attitudes, and high descent rates usually associated with the real accident. In recent years, analytical and simulation techniques have become available. These methods are discussed in the following paragraphs.

3.6.1 Analytical methods. Flight data recorders introduced in 1958 are used by air carriers (civilian transports) to record many flight qualities such as airspeed, altitude, heading, acceleration, etc. Unfortunately, flight recorders are not standard equipment for military aircraft. Recently, an additional source of data has become available to the investigator by the use of radar recordings at many Air Traffic Control (ATC) Centers. These ATC recordings can provide valuable information for the analysis of accidents involving aircraft which do not have on-board data recorders.

ATC radar records provide only aircraft position; aircraft forces, velocities, and attitude angles must be derived. The method of reference 2 uses large-angle motion equations to systematically derive the desired values. The time/history/position data $x$, $y$, and $h$ are first stored on a general-purpose digital

computer for further processing. A least-squares procedure is used to provide smoothed time histories of aircraft position (x, y, h), the inertial velocities ($\dot{x}$, $\dot{y}$, $\dot{h}$), and the accelerations ($\ddot{x}$, $\ddot{y}$, $\ddot{h}$). A transformation of the inertial velocities to ground speed, track angle, and flight path angle is possible.

3.6.2 Use of simulator techniques. Simulation techniques can be used effectively to recreate the elements of a particular accident and systematically study various factors conducive to loss of the aircraft (Ref. 3). The degree of simulator sophistication needed depends on the type of accident being studied. Six-degree-motion capability may be needed, for example, to determine the effects of a pilot's input on aircraft response in an abnormal flight situation. The acceleration feedbacks to the pilot from the simulator should closely represent the accident situation if useful results are to be obtained.

### 3.7 Examples of the Application of Analytical and Simulation Techniques in Accident Investigations

3.7.1 Use of ATC radar data in stall accident. This example shows how ATC radar data were used to calculate the flight path of an aircraft near Thiells, New York, on December 1, 1974 (see Ref. 4). The aircraft stalled at an altitude of approximately 8 km during a climb-out in IMC conditions and descended into the ground in an uncontrolled spiral dive. The stall occurred because of an erroneous airspeed readout which resulted from blockage of the airspeed measuring system by ice.

A time history of the aircraft motions obtained from analysis of the ATC radar data is presented in Fig. 1. Shown for comparison are altitude, airspeed, normal force, and heading obtained from an on-board flight data recorder.

The time (slightly after 6 min) when the pitot tube became blocked by ice is shown in the time history by comparing radar-derived (inertial) airspeed with the on-board airspeed indication. It can be appreciated how the pilot was misled into believing he had adequate airspeed margin from the stall and was thereby confused by the stall departure situation which occurred. The pitch angles derived from the radar data indicate a 27° nose-up angle at stall followed by 25° nose-down angle during the initial portion of the descent. The heading and roll angles derived from the radar data indicate the time at which roll-off occurred and the spiral descent which followed.

3.7.2 History of an "upset" accident. On May 3, 1968, a Braniff Airways, Inc., Lockheed L-188, Electra (N-9707C) approached an area of severe thunderstorms astride the airway from Houston to Dallas, Texas, at an altitude of 20,000 ft. At 1636:50 the crew requested permission to descend to 15,000 ft and deviate to the west of their intended route. At 1644:21 the flight was cleared to descend to and maintain 5,000 ft. At 1646:10 the controller asked if the crew saw any openings through the area where they were going. Flight 352 replied, "it's not clear but we think we see an opening through it." Approximately 1 min later the crew asked ground control if there were any reports of hail in the area in which they were flying. The controller replied "no" and again advised the flight that other flights had deviated to the east. At 1647:23 the flight requested permission to make a 180° turn and was cleared by the controller to make the turn in either direction. The crew acknowledged their clearance at 1647:35. At about 1648, the flight crashed approximately 1 mile east of Dawson, Texas.

It was obvious, quite early in the accident investigation, that loads in excess of the airframe strength had been imposed on the structure to cause in-flight breakup, but the nature and origin of these loads were not immediately apparent even though both the flight recorder data and cockpit crew voice recordings were available from the wreckage. Possible causes of the overload condition included an encounter with some extreme weather conditions, a combination of weather and pilot response, or only some pilot-induced maneuver. A simulator study might help determine whether the pilot could maneuver the undamaged aircraft in a manner to cause the variations in the flight parameters exhibited on the flight recorder tape where excessive loads might be expected during recovery from the extreme attitude and airspeed conditions.

Description of simulator used: The simulator cockpit was equipped with normal flight instrumentation and flight controls appropriate to a four-engine turbine-powered aircraft. For the range of aircraft flight conditions pertinent to the tests, the cockpit instrumentation accurately displayed the flight parameters developed in the computer in response to cockpit control inputs. Those characteristics of the Electra aircraft that were pertinent to the definition of the flight profile (the wing loading, drag, and spiral stability) were included in the computer program, and the lateral and longitudinal control characteristics were adjusted to approximate those of the Electra airplane.

Description of test conditions: The data obtained from the flight recorder for the last several minutes of flight are shown in Fig. 2. During the latter portion of these records the data indicate a descending right turn that resulted in a very high rate of descent and rapidly increasing airspeed. Although the flight data indicate that the aircraft was flying in moderate to heavy turbulence, no turbulence was simulated because there was no conclusive evidence of large-scale drafts of the type that would have a long-term influence on the flight path of the airplane. Further, the objective of the simulation was to obtain reasonable facsimiles of the flight-recorded values between times 36:45 and 37:15, and to document the pilot's action that might cause such a maneuver. To amplify the re-creation of the cockpit activity during a number of simulator runs, a facsimile of the cockpit voice recorder was played in the proper time correlation.

Effect of acceleration and bank angle: The most successful results of attempts to duplicate the significant aspects of the flight maneuver are given in Ref. 3. A reasonable duplication of the airspeed between times 36:55 and 37:09 and altitude between times 36:55 and 37:17 was obtained by banking the simulated airplane to at least 90° by time 37:06. Attempts to duplicate the acceleration record between times 37:08 and 37:15 with elevator inputs were only grossly successful because of the demanding nature of the simulator piloting task and not because of a dynamic limitation of the simulated aircraft. A more accurate duplication of acceleration between times 37:10 and 37:13 would merely have increased the true heading change in that period by about 10°. Thus, this simulator analysis of the flight recorder data defines the final maneuver of the aircraft as a shallow climbing turn to the right, which progresses into a steep diving turn as the angle of bank is slowly increased from 30° to more than 90°. This maneuver appears to be well within the control capabilities of the Electra airplane.

Causes of the accident: The accident investigating board concluded that the probable cause of the accident was an unwise decision to penetrate an area of known severe turbulence with inappropriate maneuvering. Turbulence may have played a part in upsetting the aircraft after the pilot started the 180° turn; however, the pilot's flight situation suggests that attitude disorientation is a more probable explanation. It is appreciated that large bank angles can be attained quite easily when turning and flying on outside visual references among large cloud formations, because of the apparent slow rate of bank-angle divergence. This lateral upset then progressed to a longitudinal upset as a result of the loss in lift.

From the simulatpr experience it was easier to understand how the pilot, in attempting to retreat promptly from an area of severe thunderstorm activity, could without a good horizon reference displace the aircraft to a large bank angle and nose-down pitch such that the airspeed rapidly approached the placard limit. Because of the pilot's concern for the proximity to the ground, a high-g pullout resulted and the wing structure was overstressed.

The foregoing example has exposed the problems and serious consequences that can result when pilots are confronted with a novel flight situation. Indeed, they may find themselves being pummeled around the cockpit as the aircraft responds in a strange and unfamiliar manner to large updrafts and downdrafts. Without a good outside reference to the real-world situation they may try to extricate themselves by inappropriate maneuvering. What is strongly suggested here is the need for a particular type of training simulator to give pilots the opportunity to explore these unknown areas with impunity, allow them to become familiar with the environmental aspects, and practice penetration and recovery techniques. The simulator requirements for this training function can be better understood by using an example of an accident in which training was the primary purpose of the flight.

3.7.3 History of a pilot training accident. On March 30, 1967, Oelta Air Lines OC-8 (N802E) took off from runway 28 at New Orleans International Airport, Louisiana, on a training flight. The crew was performing a prebriefed, simulated, two-engine-out landing approach. At 1,200 ft and 200 knots, engines 1 and 2 were set at idle power and the aircraft turned left decreasing altitude to 900 ft. At about 0048, the flaps were lowered to 25° and altitude increased to 1,100 ft as the airspeed decreased to 180 knots. During this transitional period the instructor prompted the captain-trainee on basic airmanship, "Oon't get below 160 – ball in the middle – whatever it takes." At 0049:20 as the landing checklist was being carried out, landing flaps (full down) were lowered by the instructor without verbal command from the captain-trainee. Shortly afterward, the aircraft descended to 650 ft at 165 knots, 2.5 miles from the runway; on a 2.5° glide path this would result in a normal touchdown on the runway. The crew's initial impression of the approach was optimistic as reflected in comments as "Okay, 8ud, looks good. How 'bout that." Unfortunately, the actual descent became steeper than anticipated because the increased drag created by the large flap deflection resulted in a flight path that would end short of the runway. The situation became even worse when the captain-trainee arrested the rate of descent by increasing aircraft attitude rather than adding power, with the obvious consequence of a continuing speed bleed-off. As the airspeed continued to decrease to approximately 136 knots, the need for power was finally recognized and throttles were advanced on engines 3 and 4. At this point the instructor said, "Get the rudder in there – you're getting your speed down now, you're not going to be able to get it." The trainee replied loudly, "CAN'T HOLD IT BUO" as the aircraft continued to turn and bank to the left. The control tower operator observed that the bank angle was 60° or greater when the aircraft hit the power lines.

Simulator test procedures and equipment: Since the questions to be answered by the simulator tests were primarily those relating to cockpit procedures, the simulated approach was started at the final portion of the flight recorder trace (shown in Fig. 3) with landing flaps down, at an airspeed of 160 knots, with engines 1 and 2 at idle and 3 and 4 set to match the actual descent rate and speed bleed-off. The timing for power changes and ensuing control manipulation was obtained by playing a facsimile of the cockpit voice tape during the approach. By varying the timing slightly for the various events, it was possible to establish flight profiles closely matching those obtained from the flight recorder.

The simulator used for these tests consisted of a fixed transport cockpit fitted with conventional transport-type cockpit instruments. The outside-world visual scene was provided by a projected closed-circuit television picture of a model landscape and runway. Conventional cockpit controls and thrust levers were used with deflection and forces set to be typical of a DC-8 transport aircraft.

Results of simulator studies: After a few simulated approaches, the significance of several aircraft configuration settings became readily apparent. Selecting landing flaps well before landing touchdown was assured had the deleterious effects of steepening the glide path and a more rapid airspeed bleed-off. There were thus two serious consequences. First, increased power was needed to make good the intended touchdown point on the runway. This was not serious enough in itself; however, because of the nature of the training mission, power was added to engines 3 and 4, increasing the existing asymmetry. Second, by virtue of the slower airspeed, the moments due to power were greater and the roll and yaw control powers needed to counteract the moments due to sideslip and thrust asymmetry were reduced. A typical time history of these events is shown in figure 4. Note how rapidly the bank angle and the heading diverge after power was applied to engines 3 and 4 even though full rudder and roll control were applied to counteract this tendency. Note also the rapid speed decay due, in part, to the fact that the vertical fin on this class of aircraft stalls at approximately 14° of sideslip after which the drag builds up rapidly as the aircraft moves sideways through the air.

The foregoing has shown that the simulator can effectively reproduce the condition of a training accident, suggesting that pilot familiarization and training for a two-engine-out approach could be conducted on a piloted simulator instead of in real flight because of the extreme hazards involved in making actual approaches and touchdowns.

## 4. CONCLUOING REMARKS

Effective engineering procedures have been developed to conduct aircraft accident investigations. Well documented accident reports can be used to reveal trends in causes of accidents, thereby establishing the

potential for reducing accidents by appropriate aircraft design changes, operational procedures revisions, or other corrective means.

Most accidents result from human failures of some kind, failures not necessarily always associated with the person immediately involved in the accident, but possibly with people involved in the development of the system in question. Human factors mishaps can be minimized by following well-thought-out standard operating procedures which in many cases have been revised and updated from accident investigations.

Recent improvements in analytical and simulation techniques have greatly aided the investigation process. Techniques which have been particularly helpful in military aircraft accidents where no flight records data are available include the use of ATC radar records and piloted motion simulators. ATC radar information can be analyzed to provide time histories of aircraft position, velocities, forces, and attitude angles. Piloted simulators are particularly helpful when there is a question of pilot action relating to unusual aircraft behavior.

REFERENCES

1. U.S. Naval Safety Center: Handbook for Aircraft Accident Investigation. NAVAIR 00-80T-67. 1973.

2. Wingrove, R. C.; and Bach, R. E., Jr.: Aircraft Motion Analysis Using Limited Flight and Radar Data. J. Soc. Flight Test Eng. May 1980.

3. Bray, Richard S.; and Anderson, Seth 8.: Simulation Techniques Used in Investigating Aircraft Accidents. RAES/CASI/AIAA International Conference on Atmosphere Turbulence, 18-21 May. London, U.K. 1971.

4. Wingrove, Rodney C.: Accident Investigation-Analysis of Aircraft Motions from ATC Radar Recordings. NASA SP-416, pp. 179-190, October 1976.

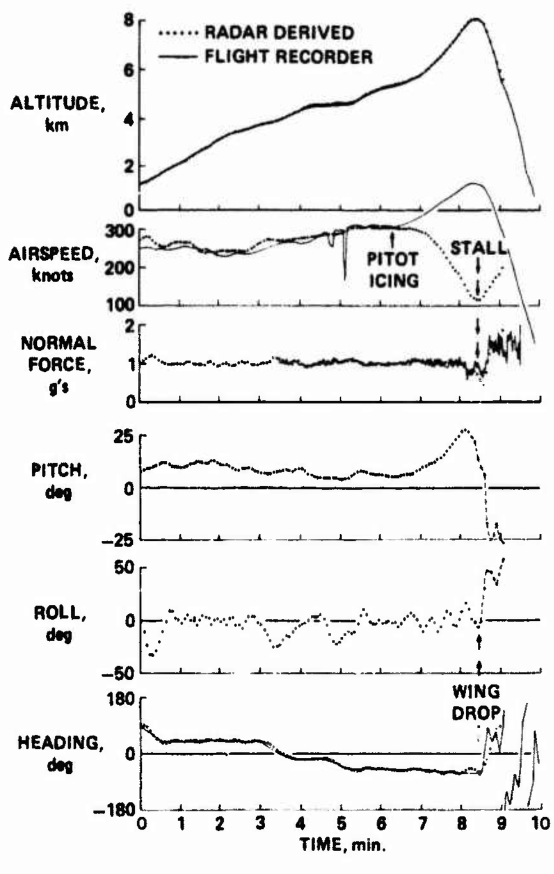


Fig. 1 Data from actual accident.

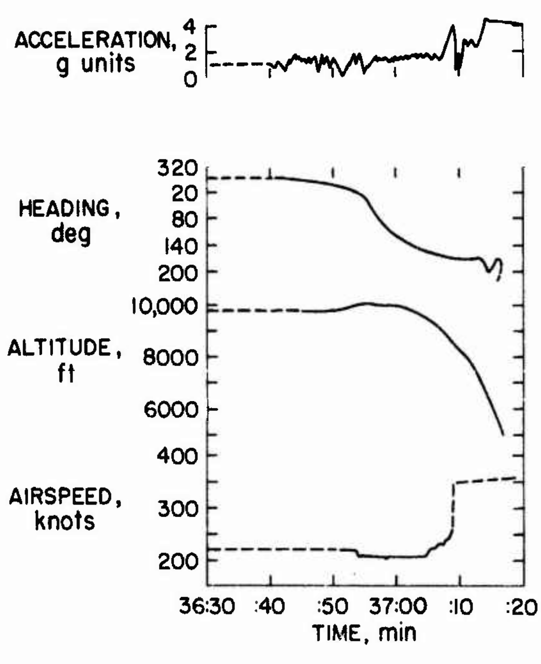


Fig. 2 Flight recorder data from Electra accident.

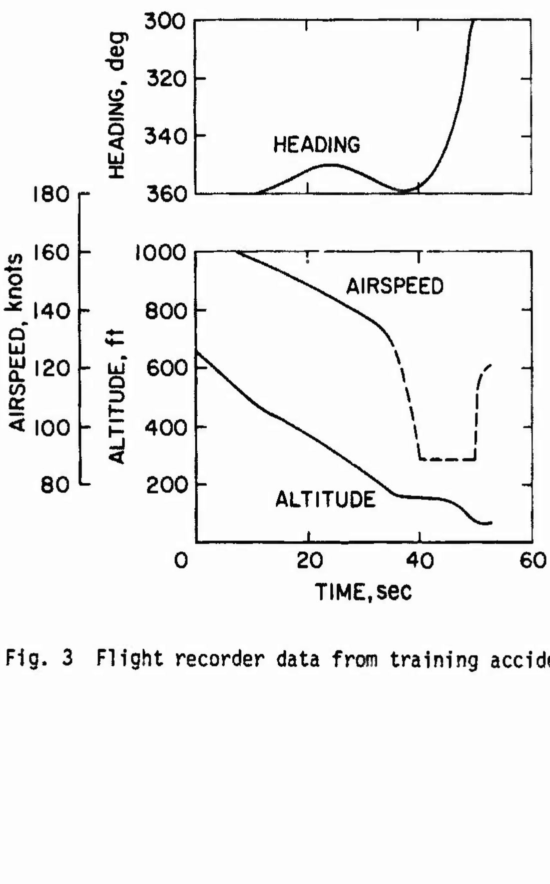


Fig. 3 Flight recorder data from training accident.

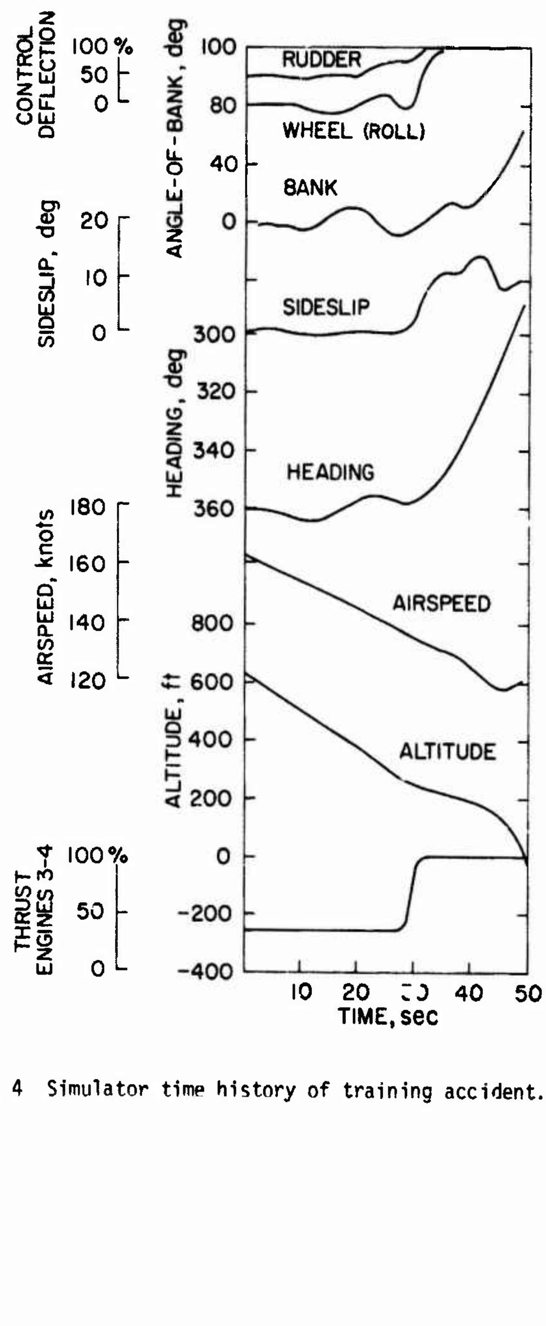


Fig. 4 Simulator time history of training accident.

# LIFE SUPPORT, RESTRAINT AND EJECTION SYSTEMS INVESTIGATION

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The examination of life support, restraint and ejection systems is an integral part of the investigation of any aircraft accident. It is important that it should be conducted in a thorough manner and particular care should be taken in the field phase of the investigation as much of that evidence is, by its nature, ephemeral.

## THE ACCIDENT SITE

### Accident location

The precise location of the accident site should be established. This can be achieved by plotting distance and bearing of the site from known positions or by analysis of aerial photographs in conjunction with a suitable large scale map. The location of the site is normally ascertained by the main accident team, but when escape system components are scattered over a wide area (sometimes several kilometres) the process has to be repeated for each item.

### Photography

Photographs should be taken as soon after the accident as possible and before the wreckage or any bodies have been disturbed. It is desirable that the investigator should be able to take his own photographs as this saves a considerable amount of time. The location and direction of each photograph should be recorded. Particular attention should be paid to the following subjects:

Fixed seats and restraint systems

Escape system components

Impact marking

Personal equipment

Injuries - either on survivors or fatalities

Fire damage.

The type of camera used is a matter of personal choice, the use of both a 35mm single lens reflex camera with colour film and a Polaroid camera has considerable advantage.

## WRECKAGE DISTRIBUTION CHART

This will normally be the responsibility of the engineering member of the accident team. The escape system investigator should however be prepared to make his own chart of the escape system components, and this is normally accomplished for compact sites by taking distance and bearing measurements from a single datum position, most frequently the front edge of the impact crater. When the wreckage is scattered, a base line can be laid out along the wreckage trail and measurement can be made by offset from this trail. When items are very widely scattered, as may happen for a medium to high level ejection, the location of each item has to be established as for the accident site itself.

## EXAMINATION OF IMPACT MARKS AND DEBRIS

Examination of impact marking and debris is vital. At accidents where the adequacy of fixed seating and restraint systems is being examined the impact marking and debris will furnish evidence of the type of impact and the pattern of break up. Careful inspection together with engineering evidence should allow an estimate of the initial velocity to be made, and from this, and the impact marks, G loading may be estimated. Together with the engineering member of the Board of Inquiry, inertia and crash switches in the aircraft can be checked, and these may provide additional supporting evidence for the crash loads.

When investigating escape systems, impact marking may show the attitude and direction of the ejection seat at first ground contact; this is important in the analysis of 'on the edge of the envelope' ejections and in escape system trajectory reconstruction.

In addition to ground contact marking, impact marks may also furnish evidence of contact with other parts of aircraft structure, either within the cockpit or against other parts of the aircraft.

## INVESTIGATION OF THE ESCAPE SYSTEM

The purposes of the escape system investigation are:

1) to establish evidence of system initiation
2) to establish ejection conditions
3) to establish evidence of normal sequential function
4) to relate any injury sustained to the appropriate part of the escape sequence

5) to relate any equipment damage to ejection conditions

6) to provide accurate data for flight safety and design purposes.

The following comments apply only to Martin Baker escape systems but the underlying principles can be applied to all ejection seats.

1) Evidence of system initiation

Since under certain circumstances some ejection seats can be initiated as a result of the impact, it is important to determine that the escape system has been voluntarily initiated.

a. Cable operated systems

Displacement of the initiating handle from its housing, withdrawal of the main gun sear, and 'normal' marking by the latch mechanism on the latch frame is normally regarded as evidence of an initiated ejection.

b. Gas operated systems

Displacement of the initiating handle from its housing, together with withdrawal of the main gun sear, and normal latch frame marking, coupled with the presence of explosive residues underneath the piston for the cross-shaft assembly and in the gallery of the power shouldar retraction reel, give strong presumptive evidence of voluntary system initiation.

When canopy jettison is linked to ejection initiation, there is normally a fixed time delay of 300 milliseconds between the start of canopy jettison and firing of the ejection gun. Under these circumstances evidence of normal operation of the canopy jettison system is additional confirmatory evidence of voluntary initiation. Similar considerations apply to command ejection systems.

2) Ejection conditions

These may be derived from several different sources. The pilot or crew's narrative account of the accident may well give the height, speed, altitude etc, of the aircraft at the time of ejection, although very often these will be the last conditions remembered, rather than the conditions actually at the time of leaving. Where Flight Data Recorders (FDR) are fitted it may be possible to get ejection conditions with greater accuracy either by an ejection marker signal on the FDR trace, or by the pitch change associated with the ejection seat leaving the aircraft. Occasionally the ejection may appear on film and this enables an analysis to be undertaken, although the process is far from simple. Witness markings on the guide rails on the ejection gun may give clues as to the aircraft attitude at the time of escape. Finally if the position of the escape system components on the ground are known with accuracy (which they should be if the mapping has been done properly) it is possible, knowing the performance characteristics of the escape system, and assuming an initial set of ejection conditions, to conduct an iterative process on the computer to provide a "best fit" set of figures for the escape.

3) Evidence of normal sequential function

This is the continuation of the process used to establish evidence of system initiation. The operation of drogue systems to stabilise and retard the seat is checked, followed by evidence of harness release, seat separation and parachute deployment. The condition of the drogues and the main parachute may provide confirmatory evidence for the ejection conditions. Where the escape has not been successful due to a late ejection it is sometimes possible to establish when the sequence was terminated by witness marking on either the rack of the drogue gun or time release unit timing mechanism. Similarly where impact has stopped full time release or drogue gun firing mechanism run out, the position of the mechanism can be found by X-ray and tha time at impact deduced. Timing can sometimes also be gauged by the pattern of burning of multi-tube rocket motors. The lugs of the restraint and parachute harness should also be examined for evidence of engagement in the seat harness locks. (See examination of restraint system.)

Impact ejection

In this case the canopy jettison and command ejection system may show signs of abnormality. Typically there is a difference in the sort of marking made by the latch plunger on the latch frame; since to separate the seat from the gun, the top of the latch frame has to break away. Under these circumstances ejection gun firing may be abnormal and one or both of the secondary cartridges may be unfired.

4) Injuries

The investigation of injury requires a close link with both the clinicians in charge of the case and where appropriate the pathologists.

i. Due to assisted escape

Injury may occur at different points in the escape sequence and the types of injury are often characteristic. They may be summarised as follows:

a) Injuries occurring as a result of explosive canopy disruption i.e. Miniature Detonating Cord systems.

These injuries are due to lead spatter from the explosive cord and may range from penetrating eye damage and traumatic tattooing, to an insignificant dusting of the skin, depending on the degree of protection afforded to the occupant, and his proximity to the cord at the time of detonation.

b) Due to ejection gun fire.

This may produca the characteristic compression fracturing of vertebrae within the thoraco-lumbar spine. This has been extensively documented alsewhere. Very rarely mid shaft femoral fractures may be seen due to incorrect leg positioning at ajaction.

c) Due to through canopy ejection.

Through canopy ejection may increase the incidence of lowar spinal injury due to ejection gun firing and may also produce injuries in the cervical spine and sternum due to forced hyparflaxion of the head.

d) Due to exposure to windblast.

Leg flail occurs from a speed of approximately 200 kts upwards when the legs are unrestrained and arm flail from approximately 350-400 kts upwards. On very high speed ejections there has been the suggestion that distraction injuries of the neck may occur due to helmet lifting forces and at least one air force has reportad blast damage to the lungs.

e) Due to drogue or parachute deployment.

Since the decelerative forces on the man due to drogue or parachute deployment are input to the man through the harness, the head and neck are vulnerable to sudden snatch loading. In consequence upper spinal injury may occasionally occur. Head injury due to impact with the ejection seat following halmet loss may also be seen.

f) Due to parachute landing.

Parachute landing injurias vary from thoracic-lumbar spinal compression fractures to limb and joint fractures. Head injuries may result from ground impact following helmet loss on ejection and may be seen even with helmet retention following an extended parachute drag over rocky terrain.

ii. Injuriea due to unassisted escape

Injury may occur due to canopy jettison and striking parts of the aircraft during the escape. Other injuries may occur due to parachute deployment aad parachuta landing.

5) Equipment damage

The crew's clothing should be recorded, examined to determine its integrity, and any damage or defecta recorded. Where possible damage should be related to ascape systams operation e.g. boot scuffing or cutting as a result of striking items within the cockpit during the aarly part of the escape sequence. Items of protective equipment such as lifepreservers and immersion suits should be tested for correct operation even when they have not been used; and where they hava been used, evidence of correct function should be sought.

Helmets should be examined and the essential information detailed at Annex A should be recorded.

## IMPACT INJURIES ON FIXED RESTRAINT SYSTEMS

Where the aircraft was occupied at impact, injury may occur eithar as a reault of the deceleration alone, or from the deceleration plus a aubsequent strike against part of the aircraft structure. It is important in these cases to assess the maintenance of cockpit volume, and the adequacy of the restraint system.

## EXAMINATION OF RESTRAINT AND PARACHUTE HARNESSES

Tha examination falls naturally under three headings:

1) Examination of the attachments
2) Examination of the harness
3) Examination of the fastening(s)

It is necessary to examine the seats and their attachments as part of this investigation and this should be done in conjunction with the relevant engineering specialists.

1) Attachments

In aircraft without escape systems the attachments for the harnesses should be to aircraft strong points. These attachments should be examined for evidence of distress or failure and the condition of the harness webbing leading from them should be noted. Some harnasses are located only to the seat, reliance being placed on tha seat attachments to react the harness loads. These seat attachments should be examined very carefully as although the static strength calculations may indicate that the attachments are adequate, no note is taken of the effects of airframe structural deformation. Cases have occurred where the aircraft has 'sprung' enough to releasa the seat attachments and then gone back to its original position.

The condition of the inertia or retraction reel should be assessed. Attempts should be made to establish whether the harness was fully retracted and if it was locked. Where injuries have occurred that appear to be due to poor upper torso restraint, the upper torso harness geometry should be assessed together with the freedom of 'take-up' on the inertia reel, inertia reel spring tension and harness routing.

On ejection seats the harness lugs which attach to the harness locks should be examined, and in cases where the pilot was still attached to the seat at impact, these lugs may show evidence of ovalisation. This provides confirmatory evidence of an impact above survivable limits.

2) Examination of the harness

The harness should be examined for evidence of damage and its condition should be noted. The harness adjustment is frequently changed in the process of removal from the subject but its position at the time of impact can sometimes be established by the presence of 'set' marks in the material where it has been gripped by the adjustment buckles. The adjustment of the harness should be related to body size, which should be known from the individual's anthropometry.

3) Examination of the fastenings

The quick release fastening should always be checked for integrity as it is not uncommon to find evidence of inertial or inadvertent release. This is particularly true of some civil harnesses but it may also occur with certain military fasteners.

Note should be taken of any difficulty of operation, as the release forces on some fittings are a function of the load applied across them. This can lead to problems in separating from the parachute when being dragged under high surface wind conditions.

EXAMINATION OF THE CREW

This will have been done by the Flight Surgeon or Flight Medical Officer first involved at the accident. It is important, however, that the investigator should examine the injuries at first hand, as this avoids the problem of interposing a different judgement as to causation. Where possible a full narrative history of the emergency and the escape should be obtained, and careful note should be taken of the memory for various parts of the escape sequence, so that the presence and duration of any impaired consciousness can be determined. If there is any evidence of impaired consciousness, note of any head or neck injury should be taken, including Xrays, and a full neurological examination should be conducted. Full notes of the clinical condition of the subject must be recorded.

The post mortem examination by the pathologist should be attended and note taken of any injuries. In cases where the escape system appears to have functioned normally, but the ejectee has failed to survive, particular care should be taken in looking for evidence of incapacitation prior to death. A careful dissection of the cervical spine should be carried out under these circumstances.

EXAMINATION OF OXYGEN AND PRESSURISATION SYSTEMS

Oxygen and pressurisation systems tend only to be examined post accident when the circumstances indicate that a malfunction may have occurred. Their examination follows the same lines as for any other aircraft system and consists of checks to attempt to determine functional integrity and control setting. In certain cases it may be possible to demonstrate the presence of ante mortem hypoxia, but this requires careful discussion with the pathologists.

REPORT WRITING AND DOCUMENTATION

The final report is a vital document, since it is the only lasting record of the accident. It should be complete and accurate since it is upon cumulative reports that the evidence for prevention studies and flight safety improvements are based. It is necessary sometimes to record absence of evidence as well as presence of evidence and a very clear distinction should be drawn between recorded facts and interpreted causes. This is necessary since experience over a number of accidents may change the interpretation of evidence and a failure to distinguish clearly between interpretation and fact does falsify accident statistics. It helps to have a standard format for recording information and NATO Stanag 3318 is suitable for this purpose. Whilst 3318 is useful for recording, it does not serve as the basis for a report to a Board of Inquiry, and the author uses the format shown at Annex B.

FACILITIES AND EQUIPMENT NEEDED - See Annex C.

REFERENCES

1. International Civil Aviation Organisation. Manual of Aircraft Accident Investigation. DOC 6920-AN/855/4 Fourth Edition 1970.

2. US Army Research and Technology Laboratories Aircraft Crash Survival Design Guide. USARTL-TR-79-22D.

Information to be recorded on helmets

a. Helmet Code number for future reference. Subject details.

Evidence of retention and configuration, chin strap, mask and visor positions.

Type and size of helmet, degree of fit, special modifications.

Photographic recording. Full coverage of shell.

Details of specific areas.

Full description of helmet damage.

Shell and visor

Lining/suspension tapes

Neck strap/break links

Associated equipment - oxygen mask, ear protectors etc.

b. Incident Date

Ejection/crash/mid-air collision/other incidents incurring damage.

Brief account of incident containing all the information relevant to head impact.

Pre-incident position of the visor.

Description of any objects known or thought to have been struck by the head. Canopy, instruments, ground, escape systems, etc.

Windblast. Details of loss or movement of the helmet, if applicable.

ANNEX B

SAMPLE FINAL REPORT FORMAT

## The Factual Report

### Circumstances of the accident

This is a brief narrative of the events leading up to the accident, a description of the accident and its location, and an outline statement (where applicable) of whether escape was successful or not.

### Weather Conditions

### Crew

A list of the crew involved.

### Injuries

A detailing of any significant injury occurring. Where relevant this would also include an outline of the important post-mortem findings.

### Personal Equipment (AEA)

A list of the equipment worn together with its condition.

### Distribution of Wreckage and Escape System Components

This is normally presented as a map in an Annex to the main report. Occasionally a description is added.

### Condition of the Escape Systems

A detailed description of the condition of the various items; and would include as subheadings condition of the parachute, its harness, and the restraint system.

### Analysis

Under analysis the evidence recorded is drawn into an assessment and evaluation of the most likely sequence of events. This leads to the formulation of various hypotheses which may be tried and rejected. Causes of rejection should be noted. When a conclusion is drawn which is an expression of opinion rather than irrefutable fact this should be clearly indicated.

### Conclusions

#### Findings

#### Causes

### Safety Recommendations

<u>In the field</u>

Adequate protective clothing

Identification papers

Large scale maps of the area of the accident

A good magnetic compass

A steel measuring tape at least twenty metres long

A pocket calculator, protractor and dividers

Grease pencil or indelible marking crayons

Writing materials, notebooks and labels. (Dictaphone)

A strong multipurpose knife

Pocket lens and small mirror

Heavy twine or cord

Flag markers

A waterproof electric torch with spare batteries and filament

Photographic equipment

Small first aid kit

Copies of relevant documentation.

<u>In the laboratory</u>

Photographic equipment

Stereo microscope

Table for laying out parachute

Storage space

Access to: Technical literature<br>
Workshop facilities<br>
Manufacturers<br>
Forensic laboratory

# AIRCRAFT ACCIDENT INVESTIGATION AND THE FLIGHT SURGEON

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USA

Physicians practicing aviation medicine may be called upon at any time to participate in the investigation of an aircraft accident. The flight surgeon is obligated to provide the accident investigation board with an accurate and complete report including findings and constructive recommendations. However, in order to do this, an understanding of investigative techniques as well as a basic knowledge of aircraft, life support systems, survival equipment, and aviation pathology is necessary.

This paper describes for the flight surgeon the essentials of aircraft accident investigation. Although what is written herein is intended primarily for the military flight surgeon, much of its instruction has relevance for the investigator of commercial and general aviation accidents. In any case, the flight surgeon's role is to determine the cause of injury/death, to decide if egress/life support equipment functioned properly during the escape, survival, and rescue sequence, and to ascertain if there were medical or human factors which contributed to the accident. How the flight surgeon fulfills this role is the subject of this review.

## INTRODUCTION

Physicians practicing aviation medicine may be called upon at any time to participate in the investigation of an aircraft accident. The flight surgeon is obligated to provide the accident investigation board with an accurate and complete report including findings and constructive recommendations. Aircraft accident investigation requires knowledge and skill. Knowledge of investigative techniques is acquired from the classroom as well as from reflective study of the literature. However, acquisition of the skill (as well as style) of aircraft accident investigation is quite another matter--it must be developed and refined with experience; it simply cannot be instilled in a short course of instruction. What is expected of novice flight surgeons, however, is a thorough understanding of the basic principles of aircraft accident investigation as well as adequate preparation (before the accident occurs). This should provide the flight surgeon with adequate resources to complete a constructive and useful medical investigation.

When one considers the nature of military flying, for example, aerial combat maneuvers, air-to-ground weapon delivery, air-to-air refueling, formation flying, and low level navigation, it becomes clear how important flying safety programs and aviator professionalism are. However, in spite of even the very best of flying safety programs, the nature of military flying is inherently risky. Although prevention programs have resulted in marked reductions, some aircraft losses and aircrew ejections can be anticipated.

When accidents do occur, they must be investigated thoroughly in the hope that whatever information is revealed will help prevent a recurrence. As stated so well in a USAF manual, "The purpose of an aircraft accident investigation is to determine all factors, human and material, which directly or indirectly contributed to the accident. This information can be used to . . . prevent recurrence of similar accidents. Each accident investigation adds to the overall USAF accident experience, providing a basis for corrective action. The proper use of accident experience results in elimination of accident potentials."[1]

## ROLE OF THE FLIGHT SURGEON

Aircraft accidents are due to either human factors such as illness, disability, or errors of judgement; mechanical factors such as material failure; or environmental factors such as weather. Therefore, in order for an aircraft accident investigation board to have a full spectrum of expertise, its voting membership should include not only pilots and maintenance officers, but also a flight surgeon.

The flight surgeon's role is to determine the cause of injury/death, to decide if egress/life support equipment functioned properly during the escape, survival, and rescue sequence, and to ascertain if there were medical or human factors which contributed to the accident. How the flight surgeon fulfills this role is the subject of the ensuing pages of this review.

## PREPARATION

One of the keys to successful aircraft accident investigation is preparation. The flight surgeon who makes an extra effort to be prepared will be better able to respond quickly and efficiently should an accident occur. This effort will, undoubtedly, contribute to a better final product. Preparation cannot be over-emphasized since accidents always seem to occur at times least expected and at times of the greatest inconvenience. The following are suggestions to the flight surgeon which will help ensure readiness should the unexpected occur.

a. Designate a ready access area in a convenient location of the Flight Surgeon's Office for the paraphernalia that a flight surgeon might need for aircraft accident investigation. The accessibility of these supplies would then permit the flight surgeon to respond expeditiously to an accident whether it occurs during the day or in the middle of the night. Regardless when an accident occurs, the flight surgeon must be ready to deploy immediately with supplies to the accident site. Groping for them, particularly in a deserted hospital at night or very early in the morning, is a poor way to begin.

b. In the designated ready access area, pertinent organizational regulations and publications concerning accident investigation which will assist the medicsl officer must be maintained. In this way the investigator will have ready reference to unit policies and procedures which will serve as a guide for an accurate and complete investigation report. Other textbooks and journal articles germane to aircraft accident investigation should also be kept on file. If this is done, the flight surgeon will have a ready-reference library from which useful information can be extracted.

c. Medical investigstor kits should be prepacked, stored, and ready for immediate use. The number of kits and the extent of their contents must be determined by the flight surgeon based upon the flying mission, the nature of the surrounding area, and the type of aircraft that moat frequently takes off and lands at that particular base. For example, a base which accommodates high-performance single-seat aircraft and is located near a metropolitan area hss potentially different investigation problems than a transport air base, situated near rugged hill country, where large aircraft are coming and going. More will be said in later paragraphs on the contents of these kits.

d. To be an effective and efficient investigator, the flight surgeon must do far more than have neatly tucked away publications and a complete investigator's kit. An important part of preparation is training. Flight surgeons should periodically attend courses in aircraft accident investigation. (There are several such courses in the USA which teach not only the basics, but also aspects of aviation pathology.) Furthermore, at least one basic textbook should be read as well as pertinent journal articles. In addition, flight surgeons should be required to review periodically organizational rules and regulations as well as the various forms governing aircraft accident investigation. Only in this way--by maintaining familiarity with investigative procedures and with the role of a physician investigator--will the flight surgeon be well prepared and well rounded academically.

e. Flight surgeons must be familiar with the structural features of the aircraft, the egress system, and life support equipment utilized by the flying unit. Additionally, the flight surgeon must know the nature of the flying missions and portions of the missions which are especially demanding on both the crew and the aircraft. This knowledge is best gained by flying periodically on the unit aircraft and by discussing the mission with pilots. Furthermore, periodic visits to the egress and life support facilities, discussions with facility personnel, and reviewing the aircraft systems manual and various technical orders dealing with the egress/life support systems are encouraged. Only in this way can the flight surgeon understand this equipment and its operation and be able to identify deficiencies. When suddenly called to the field following a crash, the flight surgeon must already be very familiar with those systems.

f. The flight surgeon must become acquainted with flying safety and life support personnel and should attend their meetings. This is another way that the flight surgeon can learn more about the mission, safety, and life support problems and can also establish good rapport with those individuals with whom he would be working in the event of an aircraft accident.

g. Flight surgeons should read over old aircraft accident reports which are on file. These reports can be very instructive in that they represent examples of completed formats of previous investigations.

h. Ensure that paramedical personnel, who may be called on to assist, remain current in aircraft accident investigation procedures. These technicians frequently provide invaluable assistance to flight surgeons, particularly in those accidents involving large numbers of personnel. Although technicians are not voting members of the board, they may participate with the flight surgeon in the investigation.

## AIRCRAFT ACCIDENT INVESTIGATION MEDICAL FORMS

The medical portion of the aircraft accident investigation report must be completed on some type of form, the format of which will vary somewhat from organization to organization. The design of the format is not important in itself as long as it clearly and logically provides complete information addressing the entire accident sequence including egress/ejection, survival, and rescue. A good investigation form will help the flight surgeon whose task it is to gather, to sort out, and to analyze a considerable amount of data. It would be worthwhile, as part of training, to review periodically this form in order to ensure familiarity with its content and format. Then, suddenly confronted with an accident investigation, the flight surgeon will at least have a preconceived notion of how to proceed.

A word of caution: flight surgeons frequently feel compelled to "fill in" all of the blocks as quickly as possible. This compulsion should be resisted lest the investigation be an unthinking pursuit of unrelated details. Rather, view the accident from the heights, integrating and correlating all of the available evidence, and use the form only as a vehicle for recording information. The following is recommended data which should be gathered and compiled on any accident investigation form regardless how the form itself is structured.

a. Flight Data: This section should address weather and environmental conditions. This information could be provided by survivors or from secondary sources.

b. Medical Information: Medical information is of particular interest to the flight surgeon. All injuries must be identified, their cause determined, and an estimate of when they occurred during the accident sequence. Only by such an analysis can recommendations be made to prevent similar injuries in the future. Diseases or defects present at the time of the mishap must also be noted since they very well may have contributed to the accident. This requires that the medical records of all aircrewmembers be reviewed in detail. It is also important to know whether or not the aircrewmember was flying with a medical waiver, since it must be determined if the waived medical condition contributed to the accident. (This information may help determine if waiver policy is too liberal or too conservative.) All lab, x-ray, and autopsy results should also be included in this section.

c. Psychophysiological and Environmental Factors: This section is extremely important in that these factors have been and continue to be contributory to a significant number of accidents annually. They are generally considered under the rubric of human factors and include, for example, supervision, cockpit design, communications, illness, personal problems, and a host of other stresses of flight. Each of these factors must be considered in relation to the accident, escape, landing, survival, and rescue. This is a particularly tedious portion of the flight surgeon's investigation because causal relationships of some of the factors are extremely difficult to prove. Examples include boredom, inattention, overconfidence, distraction, lack of confidence, task overload--all of which can be implemented only by supposition. Therefore, the investigation of human factors will put the flight surgeon to the test.

d. Personal Data: Information in the crewmember's flight and personnel records concerning flying experience, schools attended, and training should be included in this section. These data may be useful if the flight surgeon feels inadequate flying experience or training were contributory factors. Also included in this section are anthropometric measurements which can be a factor in ejections from small cockpit aircraft by crewmembers who are unusually tall or with excess sitting height. A portion of the personal data should be given to a chronological account of activities for the 72 hours just prior to the accident for all crewmembers. Oftentimes a detailed history will reveal improper sleeping, eating, or drinking, for example, which may have a bearing upon the mishap.

e. Personal, Survival, and Escape Equipment: The medical investigator should have assistance from life support personnel in completing this section. All life support equipment which the aircraft and crew carry must be identified and must be discussed regarding its availability, its use, and its proper function during all phases of the accident sequence, i.e., accident, escape, landing, survival, and rescue. In the event there were any discrepancies in the use or function of this equipment, an explanation with recommendations should be included in the flight surgeon's comments and analysis.

f. Egress, Survival, Ejection, Bailout: The escape sequence whether by ground egress, ejection, or bailout must be investigated in detail. Consequently, an adequate portion of the investigator's form should be accorded to this phase of the investigation. Conscientious completion of this section will help identify escape problems and will permit constructive recommendations.

g. Survival and Rescue: Survival and rescue are part of the accident sequence and, therefore, must be fully investigated. This section should address all aspects of survival and rescue: environmental conditions, appropriate use of equipment by the crew, and rescue operations. Any problems or difficulties must be identified with appropriate comments and recommendations.

h. Flight Surgeons Analysis and Recommendations: This section is the single most important part of the medical investigator's form. It is in this section that the flight surgeon summarizes his findings, analyses, and recommendations regarding the accident, egress, survival, and rescue sequence. All pertinent findings in the preceding sections of the form should be discussed in detail. And this analysis should include not only those findings of direct relevance to the accident, but also those deficiences which are only incidental. Because by correcting today's incidental finding, tomorrow's accident may well be prevented.

## MEDICAL INVESTIGATOR KIT

Although flight surgeons are free to design their own investigation kits, the following is a suggested kit which can be modified accordingly. Actually there should be two types of kits. One would contain minimum supplies most suitable for on-base accidents involving small aircraft or for physiological incidents. Waterproof plastic bags serve well as containers for the contents. Although the exact contents are at the discretion of the flight surgeon, the following minimum items are recommended: the medical investigators aircraft accident investigation form, vacu-containers, needles, tubes for collecting blood specimens, tourniquets, lab and x-ray request forms, paper, and pencils. More could be added, of course, but these items should be enough to begin the investigation of most aircraft accidents. As many of these kits should be prepacked as might conceivably be needed: perhaps 6 to 10 on a fighter base and 20 to 30 on a cargo/transport/bomber base.

A second type of kit could be designed more suitable for deployment to off-base accident sites or for more serious accidents in which there are several or many casualties/fatalities. This kit could contain, in addition to the contents of the waterproof plastic bags described in the preceding paragraph, such items as flashlights, scissors, pocket knife, metal stakes, twine, tape, and heavy leather gloves. Perhaps two or three such kits housed in an appropriate bag would be sufficient for most bases.

It is strongly recommended that camera and film as well as a portable cassette recorder be readily available. Photographs at the accident site can be extremely useful for the flight surgeon investigator. Likewise, a cassette recorder can be used by the investigating team at the accident site to obtain statements from surviving crewmembers or witnesses when the events are still clearly in mind.

Prepacked kits such as these stored in a designated area are invaluable to a flight surgeon who must deploy quickly to an accident site. On hand would be the investigation form and the necessary supplies to begin the investigation on the shortest notice.

For further suggestions as to the contents of the above kits, the reader is referred to a USAF School of Aerospace Medicine review entitled Aircraft Accident Medical Investigator's Kit.[2] This excellent publication provides many ideas of which each flight surgeon must make selections based upon preference and anticipated need.

THE AIRCRAFT ACCIDENT INVESTIGATION BOARD

When an accident occurs, a flight surgeon will undoubtedly be appointed as a member of the aircraft accident investigation board. In some cases, he may be assigned to the same base as the accident aircraft; in other cases, he may be sent from another base. In any event, it is most important that the flight surgeon is already familiar with the type of aircraft involved. Furthermore, the medical member of the board should be fully dedicated to the investigation. If the flight surgeon is allowed to spend only a portion of his time with the board in order for him to continue with his hospital duties, in most cases, the accident investigation duties will suffer. For the very best product, total immersion in the accident board proceedings is mandatory. And this is achieved only by full-time presence with the other board members. In general, most investigations last two to six weeks.

Exactly how a board functions depends very much upon organizational directives and the modus operandi of the board president or chairman. Usually, the board is given a work area, secretarial support, and whatever other administrative support is required. Each investigator goes about his business accomplishing his portion of the investigation by visiting the crash site, interviewing survivors and witnesses, and consulting with other experts and board members. Daily meetings should be held for cross talk, discussion, resolution of problems, and updating progress. These meetings are extremely important in that the investigators cannot only discuss and resolve problems, but also can provide information to one another. It provides a forum for the integration of all available information which is so necessary in constructing the sequence of events leading to the accident as well as an analysis of its cause. This lends further credence to the requirement for the flight surgeon to be 100% dedicated to the accident board proceedings.

Although the flight surgeon may be the only medical member of the investigation board, he will have to solicit assistance and consultation from other professionals. For example, assistance from egress specialists or life support personnel may be necessary in solving problems involving suspected malfunction of the ejection seat or other life support systems. In some instances, human factor specialists may also assist the flight surgeon in unraveling the paychodynamics of human error. The pathologist also plays a key role: the autopsy and analysis of body fluids may very well be the key to determining the cause of injury or of death. It is important that the autopsy findings of the pathologist and the operational knowledge of the flight surgeon be integrated in order to properly analyze various injury patterns. Furthermore, consultation with the pathologist as well as dental officers may be necessary for the identification of remains. Therefore, the young, inexperienced flight surgeon should never feel alone since he may call upon any number of available consultants.

The flight surgeon member of the board should conduct his investigation without any preconceived ideas. It is of utmost importance that he keep an open mind and not prematurely draw conclusions based upon what he has heard or upon what seems obvious at first glance. A good investigator approaches an accident as a detective approaches a murder mystery--everyone and everything is suspect. The flight surgeon must seek answers to many questions: Did any human factors cause or contribute to the accident? Did the egress and life support systems function properly? What caused death or injury? Were there any survival problems? What can be recommended to prevent a recurrence? The flight surgeon then must gather evidence in order to answer these questions. It can come from the wreckage, autopsy, survivor testimony, lab and x-ray studies, witnesses, and findings of other members of the board.

Certainly every accident is different; none ever follows a script. They may occur on or off base; on land or at sea; fighter, transports, bombers, or helicopters can be involved; some cause as many as 100-150 fatalities; others result in various injuries but no fatalities; other accidents will involve successful or unsuccessful ejections. Therefore, because of the wide range of circumstances surrounding aircraft accidents, the investigator must be flexible in his approach to the investigation. What is written in this paper, therefore, may not apply to every situation. Suggestions by this writer have been kept intentionally rather general in order to serve as a framework. Flexibility and improvisation within this given framework are essential.

THE INVESTIGATION

At the Crash Site

The flight surgeon who first arrives at the scene of an aircraft accident has, as his primary responsibility, the medical care of any survivors. Once this is done, however, and the responsibility for patient care has been assumed by other physicians, attention should then be focused upon starting the medical portion of the accident investigation. Even if the on-site flight surgeon is uncertain as to whether or not he will be appointed to the board, he must still begin at once. This collected preliminary data can always be given to any other medical officer that might subsequently be appointed to the board.

At the crash site, the flight surgeon may well discover invaluable evidence in his investigation. For this reason, nothing should be moved or removed at the accident site until the accident board members have had ample time to fully comb the area and to photograph the entire site as well as any portion of the wreckage which may be germane to the investigation. Of particular interest to the flight surgeon are: the extent and cause of injury/death; and the employment and function of the egress system and life support equipment. Because flying organizations may have many types of aircraft, each with its own systems, the flight surgeon must tailor his investigation accordingly. Consultation with egress specialists and life support personnel at the crash site is highly desirable.

Escape from aircraft can be by ground egress, bailout, ejection, or by capsule. In general, a large percentage of military accidents involve aircraft with ejection seats. However, regardless of the escape system or the type of aircraft, there are established procedures for emergency escape with which the crew must be intimately familiar. Therefore, the flight surgeon must fully investigate every detail of the escape sequence, paying particular attention to its function and to crew discipline, i.e., did the crew follow established procedures during the escape?

Flight surgeons will be challenged to determine causes of injury/death. Factors to be considered are decelerative forces, use of restraints, injury by fixed or flying objects, and the escape method and sequence. Useful information in the analysis is the position of bodies or parts thereof in reference to the wreckage and the ejection seat. Distances and directions should be noted and recorded on a large scale map. By meticulous attention to detail, injury patterns and causes of death can often be ascertained.

To give a few examples, if a pilot with multiple injuries was found one mile from the crash site with a fully deployed but partially burned parachute, it then becomes a distinct possibility that the aircraft was on fire prior to the crash and that the pilot's parachute was burned sometime during the ejection sequence ultimately causing death. This information not only helps the flight surgeon explain the cause of injury/death, but it may also be important to other board members who are trying to determine what type of malfunction occurred in flight.

Or, if a pilot was found with a severe skull fracture and the pilot's helmet was located a half-mile from the crash site, it would be reasonable to assume that fatal injuries were incurred because of helmet loss sometime during the escape sequence. But why was the helmet lost? Was it due to high Q forces? Or because the pilot had not fastened the chin strap? Perhaps other squadron members may relate that the deceased frequently flew with the chin strap unfastened. Was this carelessness the cause of death and, if so, what could the flight surgeon do to prevent recurrence?

For ejection-seat aircraft, the flight surgeon must analyze in detail the ejection sequence from the time the decision was made to eject until the pilot reached the ground. However, because of the complexity of ejection-seat firing and sequencing, egress specialists should be consulted. Questions to be addressed are: Did the aircrewmember properly utilize the egress system? Did it function as it was supposed to? Are there recommendations for improvement? Many of the answers to these questions are frequently found at the crash site. As examples, if the flight surgeon finds that the ejection seat handle(s) had not been pulled, this is good evidence that either the pilot did not attempt ejection or that he was incapacitated prior to ground impact. Or, if the handle(s) had been pulled, but there was no ejection, a faulty egress system is suspect. These are only a few examples of an infinite variety of circumstances with which the flight surgeon might be confronted. By consultation with an egress specialist, these and other such problems can often be solved.

## Survivors

Many experienced flight surgeons feel that the investigation, particularly interviewing the crew, should be started as soon as possible. Although a natural and well meant inclination is to wait until the next day to allow the crew to settle down physically and emotionally, it is advisable, if at all possible, to forego this temptation. If the crew interviews are postponed, it is possible that the survivors might forget, ignore, or even attempt to hide or distort some small, but extremely important details of the accident sequence.

Aircrewmembers, even those who have no apparent injury should be taken immediately by the flight surgeon to the hospital for a complete physical examination including appropriate x-ray and laboratory studies. There are several cogent reasons for taking the survivors immediately to the medical facility: to determine extent of injuries and to begin treatment; to extricate the crew from a chaotic crash site; and to begin the interviews.

Aircrewmembers who think they are not hurt are often found to have injuries. Therefore, an examination as soon as possible is mandatory. For example, many pilots who have ejected from high-performance aircraft and have experienced no back pain have been found to have compression fractures of the thoracic-lumbar vertebra. One study indicated that 10% of crewmembers who eject will sustain such an injury.[3] In any event, the flight surgeon must then initiate whatever treatment is necessary and must also decide whether or not there are medical reasons for temporary (or possibly permanent) removal from flying status.

Another reason for taking the crewmembers quickly to the hospital is to remove them from the tumult and excitement at the crash site which very quickly will attract a multitude of people, unofficial as well as official. Well meaning commanders, life support and flying safety personnel, maintenance personnel, and others, in their haste to learn the circumstances of the accident, will frequently deluge the aircrewmembers with questions. This is not good practice since it not only delays medical care of the survivors, but also subjects them to answering very important questions in an atmosphere of excitement and tension. Suggestions made by these people may lead to distortion of the memories of the aircrew as to what actually happened. The flight surgeon is in a position to extricate politely and legitimately the aircrewmembers in order to take them to the hospital. Once the medical examination is complete and treatment rendered, other officials can be given access to the crews in a much more controlled and comfortable hospital environment.

Although the flight surgeon has the crewmembers in the hospital primarily for medical evaluation and treatment, he incidentally has the luxury of beginning his portion of the investigation in the quietness and privacy of his office or ward. Once the medical needs of the crew have been addressed and the situation has somewhat settled, the best technique is to have each crewmember dictate (using a cassette recorder) the history of flight and the events leading up to the crash (or ejection). In this way, with the details fresh in mind the aircrew can give statements which the flight surgeon will have available to the board. This can be invaluable, not only for the flight surgeon, but also for the other members of the board. The crewmember can provide a much better history of flight if it is recorded in the quietness of the flight surgeon's office as soon as reasonably possible after the accident.

Because the flight surgeon is very concerned with human factors, he should fully investigate the preaccident behavior and environment of the aircrew. In order to do this, the crew must provide a detailed 72-hour preaccident history of their activities. Of particular relevance during that time is the eating, drinking, and sleeping history. A variety of questions come to mind. Did the pilot have a good night's

sleep the night before the accident? Was the pilot under any particular stress because of family or financial problems? Had the pilot been drinking excessively during the past few days? For example, it is quite possible that the crewmember had a serious family problem and was feeling depressed and unable to sleep well for several days. Perhaps the pilot had taken several sleeping tablets borrowed from a friend the night before the accident and was not in very good condition to fly the following day. Such information can only be ascertained by an aggressive flight surgeon who investigates in detail the environment of the crew. Not only must this 72-hour history be taken from crewmembers, but also from their family, friends, and squadron mates who were with them during that three-day period. And it should be investigated for aircrew fatalities as well as for survivors.

In addition, the medical records of all crewmembers involved in an accident should be carefully reviewed by the investigating flight surgeon. These records might reveal that the crewmember was flying with a preexisting illness or perhaps was prescribed medication. If so, was this a contributing factor? Should the crewmember have been flying at this time? It is also of interest to ascertain whether or not the individual was flying with a medical waiver for a static illness. And if so, could the accident have been caused by some indisposition attributable to the waived condition?

### X-Ray and Laboratory Studies of Survivors

Special studies are an integral part of the investigation. This includes x-rays and clinical laboratory/toxicological determinations on the survivors and decedents (this section discusses survivors only; see below for decedents). X-rays of the spine are mandatory on all aircrewmembers who had ejected from or bailed out of an aircraft. It should not be forgotten that approximately 10% of crewmembers who eject sustain compression fractures usually of the lower thoracic and lumbar vertebra. Frequently these fractures cause little or no pain and cannot be detected clinically.

In addition to x-ray studies, blood and urine specimens should also be obtained and sent to the laboratory. The purpose of these tests is not only for investigation, but also for detection of possible underlying disease that may have contributed to the accident. Laboratory tests recommended include CBC, carboxyhemoglobin, blood alcohol, blood glucose, urinalysis, lactic acid, and a drug screen. These tests may detect conditions of potential significance such as anemia, infection, carbon monoxide inhalation, hypoglycemia, and diabetes. Blood alcohol and drug screening tests should also be ordered as a routine.

Is is very strongly recommended that laboratory request forms be marked MAJOR AIRCRAFT ACCIDENT in bold print to be sure that they are not lost and that the laboratory is aware of the importance of these studies. For these reasons, the medical investigator should coordinate this with laboratory personnel well in advance. It is also most wise to retain in appropriate storage second aliquot specimens in case of loss of the original. All lab studies should be reported as soon as possible and the results entered on the accident investigation form. If a lab result is abnormal, the flight surgeon must determine why and whether or not the abnormality was a causal or contributory factor to the accident.

### Noncrew Members

The medical investigation is not necessarily confined to the aircrew itself. There have been accidents in which other support personnel have either contributed to or caused the mishap. For example, an accident could occur because of an error by air traffic controllers, maintenance personnel, or supervisors. This possibility must be considered and, if necessary, suspect noncrew members are then interviewed. As a hypothetical example, an air traffic controller may have given an aircrew faulty or erroneous information which resulted in a crash. Possibly the controller had taken antihistamines for a cold or had not slept properly for the last several days and was not alert during duty. Or, perhaps maintenance personnel had worked long hours because of operational necessity and left a tool in the engine resulting in damage and serious malfunction. Again, an infinite variety of scenarios are possible and should always be suspect by the flight surgeon.

On occasion, the flight surgeon may need to interview witnesses. For example, it is possible that somebody had seen the crash or had seen the ejection sequence. Such an on-site observer can provide the investigation board with very valuable information. Most often, such witnesses are called before the entire board so all its members may have the opportunity to ask questions.

### Survival and Rescue

The flight surgeon with life support and survival consultants must also investigate the employment and function of all life support/survival equipment. Although this equipment varies considerably from aircraft to aircraft, it generally includes parachutes, life preservers and rafts, and survival kits with such items as radios, beacons, flares, and first-aid kits. Much of this equipment is vital not only for escape, but also for survival and rescue. Did the crew use any of this equipment and did they use it properly? Did everything function as advertised? And if not, why not? What can be recommended for improvement?

It must not be forgotten that the accident sequence includes survival and rescue events and should be investigated accordingly. Although most downed crewmembers are rescued within hours, there is always the possibility that crews would have to survive in a hostile environment for days. All of these factors must be analyzed in-depth by interviewing survivors including those who took part in any rescue operations. Any discrepancies should be included in the final report with recommendations for correction.

### Fatalities

An autopsy must be done on each aircrewmember fatally injured. This autopsy is essential since gross and microscopic examinations often give clues not only of causes of death/injury, but also of preexisting disease heretofore undetected, e.g. coronary artery disease, which may have contributed to or caused the accident. It is in the best interests of the investigation board if an Air Force pathologist performed

the autopsy since he is familiar with military autopsy procedures and requirements. Furthermore, it facilitates consultation with the investigating flight surgeon, which is necessary since injury patterns can be best determined by integrating the pathologist's knowledge and the flight surgeon's knowledge of the aircraft and its escape systems.

In some cases, identification of bodies may be very difficult because of severe trauma or because of a large number of fatalities. If such a problem exists, the flight surgeon has several recourses. Because teeth are usually not destroyed in even severe accidents, dental surgeons can determine identity by comparing the deceased's dental records with the teeth found. Also, fingerprints and footprints can be used for identification. Even in accidents in which the hands and fingers are destroyed, the feet remain intact because of protective flying boots (some flying organizations maintain footprints of all aviators). If there are so many fatalities that the base pathologists are inundated, assistance must be requested through the chain of command.

Autopsy studies must be done as soon as possible after an accident since decomposition results in the formation of ethanol and aldehydes which invalidate toxicological studies. Embalming procedures, if done prior to toxicological studies, will also invalidate them.

As part of the autopsy, the pathologist must secure tissue and biological specimens for toxicological analysis since these may reveal very important information for the medical investigator. Tissue specimens should include, if possible, 150-250 grams of liver, brain, kidney, lung, and marrow, each of which should be placed in a labeled plastic bag and mailed in dry ice to the appropriate laboratory. Do not use chemical preservatives since they can invalidate various studies. Properly packed, this permits a transit time of 24 to a maximum of 72 hours. If available, blood, urine, and stomach contents should be packed and shipped in the same manner. Toxicological studies on tissue and biological specimens should include carboxyhemoglobin, alcohol, lactic acid, and drug screen.

In the event of fatalities, it is also recommend to x-ray the entire body. Sometimes important clues and unexpected injuries are revealed, such as the presence of foreign bodies or projectiles which otherwise would have remained undetected.

## HUMAN FACTORS

Over the years, accident investigation seems to have placed its major emphasis upon maintenance and design deficiencies, malfunction, and adverse environmental conditions. Although "pilot error" was also recognized as a causative factor of accidents, it was often not investigated in great depth probably because it had been so ill-defined. However, we have now reached a point where, because of advanced technology and sophisticated maintenance, most accidents are due to "pilot error"--a term which has been replaced by human factors--rather than to hardware.

Human factors have been well defined and are now given due consideration by investigating flight surgeons. Among them are supervisory, experience/training, man-machine interface, communication, and psychophysiological factors. Although we may know what human factors are, we still are far from learning <u>how</u> or <u>why</u> they cause accidents. For example, can one attribute with certainty that a short landing was due to a pilot's lack of experience? Or, was a wrong procedure followed because a pilot was distracted by personal problems, channelized attention, or task saturation? These and other similar questions challenge the flight surgeon in his role as an investigator.

Although the significance of human factors in any accident most often eludes certainty, the flight surgeon must not allow this to discourage him. Full effort must be given to elucidate and define these factors so as to permit reasonable presumptions as to their role in the accident sequence. This can be done in part by interviewing not only the survivors, but also any other individuals, such as supervisors, maintenance personnel, and air traffic controllers who were involved in any way with the crew. Perhaps the single most important facet of the human factors investigation is the 72-hour preflight history of each crewmember. The flight surgeon, in eliciting this history, should reconstruct chronologically all activities of the crew for the preceding 72 hours. This would include not only documentation of meals, alcohol intake, sleeping, and working, but all activities during off-duty as well. This information should be obtained from the crew as well as from their family, friends, and other squadron members. This detailed personal history can reveal much important information which might have had a bearing on the accident.

## DOCUMENTATION OF INFORMATION

Because the circumstances of aircraft accidents can vary infinitely and the number of aircrewmembers vary from aircraft to aircraft, the flight surgeon cannot be held to a rigid modus operandi in his investigation. Therefore, the flight surgeon must tailor the investigation and the completion of the accident investigation form according to the circumstances of the accident. With experience, most flight surgeons will develop a style.

The most important part of the flight surgeon's investigation report is the section dealing with analysis, conclusions, and recommendations. Any reasonable format and style are acceptable as long as the information is clear, complete, and accurate. One suggested format follows:

a. A short description of the events leading up to the accident.

b. A short description of the crew to include such information as crew position and prior flying experience.

c. A chronological account of activities of each crewmember for the previous 72 hours.

d. A complete analysis of the accident, egress, survival, and rescue. Pertinent information included in all portions of the accident investigation form should be discussed in detail with particular attention to problems encountered, malfunction, etc. Cover all discrepancies regardless of their relevancy to the accident.

e. Describe all medical considerations, i.e., presence of disease, medical waivers, lab and x-ray studies, and, if applicable, relevant portions of the autopsy report.

f. Conclusions based upon the aforementioned narrative.

g. Recommendations for correction of any deficiencies.

Once the flight surgeon has finalized his report, particularly the conclusions and recommendations, there should be established procedures for review by competent authority and then action for the correction of any deficiencies--the latter is really the raison d'etre of aircraft accident investigation and that is to correct deficiencies in order to prevent another accident. Furthermore, it is advisable to have a repository, computerized if possible, of all aircraft accident investigation data. By epidemiological studies of the data, it would be possible to discern various trends as well as to retrieve information which could be useful to investigators.

REFERENCES

1. Air Force Manual 127-1. Aircraft Accident Prevention and Investigation. 16 March 1972, paragraph 8-2.

2. Sheffield, P.J., et al. Aircraft Accident Medical Investigator's Kit. SAM-TR-74-43. USAF School of Aerospace Medicine, Brooks AFB, Texas. Sept 1974.

3. Aerospace Pathology. Edited by J.K. Mason and W.J. Reals. Chicago, Illinois. College of American Pathologists Foundation, 1973, p. 124.

# MEDICO LEGAL ASPECTS OF THE PATHOLOGICAL INVESTIGATION

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SUMMARY

The medico legal aspects of aircraft accidents are described from the viewpoint of a major international airline disaster as it is in such a situation that the problems are maximalised. The importance of identification of cadavers both in the legal field and in accident investigation is stressed. The pathologist should address himself to certain problems which are likely to arise in relation to who was in control of the aircraft, is there any evidence of negligence and, if so, on whose part and, particularly, did alcohol play a part? Insurance problems in passengers are discussed and mention made of the very specific problem of aviation - simultaneous death. The investigation for criminal activity is outlined, particular emphasis being placed on radiology. In view of the importance to individual families of many of these questions, a plea is made for standardisation of techniques throughout the world.

Medico legal systems vary from country to country - even within the United Kingdom we have two distinct types of organisation. But, essentially, all primary systems have it in common that their function is to establish who is dead and from what cause did they die. In some states - eg. in Scotland under the Procurator Fiscal - the same authority is responsible not only for establishing this basic knowledge but also for follow up investigations involving the police. But, even when this is the case, the investigation ceases when criminality is excluded.

It follows that the medico legal officers' interest - and the involvement of their medical advisors - following a fatal accident is only rarely concerned in the intricacies of how the conditions causing death came about. Moreover, they will take no direct responsibility for the settlement of civil legal problems - negligence is a matter to be fought out in the Courts between the principals, the payment of insurance claims is to be negotiated between the parties and so on. The medico legal investigation will, or ought to, provide the basic information from which to argue but it will do no more. Now, I have made it clear, I hope, that the science of aircraft accident investigation is a matter for experts and, if we are going to claim this expertise and, to a large extent, take over the medico legal autopsy, then we must also accept responsibility for providing other interested parties with such information as they need. And because we are investigating in depth, one would hope that this information would be equally detailed. I therefore think very firmly that the aviation pathologist must be aware of his legal commitment and of his likely involvement with the Courts.

But we must accept that the medico legal authority has the first and last word as to what shall be done with a body which has died unnaturally; his is the overriding power. Moreover, since many jurisdictions have some policy concerning the public interests and the prevention of repetition of an accident, the primary authority may have a primary interest in the accident investigation. It follows that the investigator's pathologist may be in an ambiguous position. Ideally, the medico legal authority will actually employ him as being the most suited man for the job and this very often happens - it largely depends on whether the individuals or organisations concerned have proved their worth. But sometimes there are two medical teams working and, in this case, one can only say that they are working to the same end and using the same methods; they must work together and there is no reason why they should not. In the event of a major passenger transport accident, the situation may be further complicated. Several organisations - including the country of registration, the state of manufacture and a state having a special interest by reason of its nationals having been killed - are entitled to send accredited representatives to the investigation; these may be accompanied by their experts and there is no reason why they should not include medical experts. Thus, the major international incident requires the greatest degree of cooperation in the human factors field. It also provides the most problems and, for these reasons, I propose to concentrate on the transport aircraft disaster; everything I say can be extrapolated to the smaller or single seat aircraft and to both civilian and military personnel but it will apply on a more limited scale.

## Identification

In the absence of proof of death, probate cannot be granted for execution of wills,

insurance policies cannot be paid and partnerships cannot be dissolved. In addition, switching of tickets is now so widespread that the accuracy of a passenger manifest cannot be guaranteed. Identification is, therefore, a pre-requisite of the medico legal investigation.

All police officers are trained in the value of visual identification and most will distrust any other method. However, in aircraft accidents disfigurement and dismemberment are common and, if not present, are often replaced by severe burning. Moreover, the circumstances of a major disaster are conducive to false personal assessments. It is everyone's experience that visual identification is suspect in these conditions and that it is better to employ other, more objective means. This is acceptable because, within limitations, one is not attempting an identification de novo; the process is simplified because one is trying to isolate an individual from a number of persons whose group identity is known with some certainty. On the other hand, circumstantial evidence is, itself, suspect and the arm of coincidence is astonishingly long; it is therefore strongly recommended that, whenever possible, identification by one means should be corroborated by another.

With these considerations in mind, the most useful means have been found[1]:

(a) Documents. Airline pssengers are exceptionally well documented. On the other hand, documents are easily burnt; they are virtually useless for the identification of women who get separated from their handbags; and they are easily interchanged.

(b) Clothing is often readily recognisable but specificity suffers from the widespread use of chain-store articles.

(c) Jewellery has the advantage of being fire resistant and articles such as signet rings are unmistakable. Frequent amputations limit the value of jewellery but, even so, it can provide evidence that a person is dead even if the whole body cannot be identified.

(d) Medical findings include simple observations such as the presence of scars, birth marks etc. The results of operation may have to be sought internally and constitute a good reason for autopsy. Surgical prostheses may be recovered and positively identified. The more uncommon an abnormality or surgical operation, the more useful is the finding in positive identification. Tattoos may be useful, particularly for photography to show to relatives, but it should be remembered that many of the designs used are very standardised and are unlikely to be unique.

(e) Fingerprints are often damaged in a post-crash fire but, when present, they are very good evidence of identification, fully acceptable to the Courts, in countries where they are widely recorded - eg. the USA. Even when this is not so - eg. in the UK - it may be possible to compare the prints obtained with those on the personal belongings of the suspected identification.

X-rays are invaluable in the identification process as almost everyone has had an x-ray examination in life with which to compare a post-mortem record. X-rays may reveal undiscovered objects in the cadaver which can then be recovered; they can provide comparative identification through the medium of normal structures - eg. the frontal sinuses; they can compare abnormalities such as calcified tuberculous glands; they can reveal prostheses which can be compared or recovered; and comparative dental x-rays may be as convincing evidence of identification as are comparative dactylographs.

<u>Dental identification</u>

The role of the dentist in the identification of mass casualties is so important as to warrant separate consideration. The reader is referred to the outstanding study by Stevens[2]. The teeth are fire resistant. They may be intact, diseased, conserved with various substances, missing, removed or replaced. Bridges and dentures may be characteristic or marked with an identifying name or number. The odontogram should, therefore, be virtually unique - particularly in the context of the 'known group'. There are, however, certain difficulties as regards dental identification:

(a) There must be <u>some</u> conservation work or abnormality on which to base a diagnosis.

(b) Some teeth will often be lost in the trauma of the accident.

(c) Dental charts are <u>very rarely</u> absolutely accurate particularly as to updating. Therefore, when accepting a dental identification, one almost always has to accept what are known as 'compatible inconsistencies'.

(d) There is no internationally accepted standard of correlation as is laid down in fingerprinting.

As a result, it is often possible only to make a dental identification 'as a reasonable medical and scientific probability'. As stated, however, the use of ante- and post-mortem dental x-rays may provide incontrovertible evidence of positive identification.

The organisation for identification in a major disaster.

The organisation has been fully described elsewhere[1] but, effectively, it involves a secretariat who are receiving, on the one hand, information from relatives, dental practitioners etc. in respect of missing persons and, on the other, observations made on the bodies at the site, in the laying out room and in the autopsy room. It is the function of the secretariat to compare and match these. The following are considered important points:

(a) It is essential to use standardised data recording forms. The use of these has been described by Stevens[3] but it may well be that computers may be needed in the event of a massive accident.

(b) The use of telex is dictated by the international nature of the passenger list and the time involved in collating information.

(c) The medico legal identification process must be fully integrated with the accident investigation. This is the subject of an Annex 13 recommendation.

It has to be admitted, however, that on occasion, the degree of disintegration is such that positive identification of bodies is impossible. In these circumstances, the best that can be done is to try to provide evidence that given persons are dead - this is a matter of collecting as many jaws, passports and other personalised belongings which will provide presumptive evidence of death as is possible.

## Civil legal issues

Responsibility

The question of which pilot was at the controls at the time of the accident may be of great importance. An examination, including x-ray, of the hands and feet may give valuable clues[4].

Negligence

The possibility of negligence is bound to come up after any accident and this may extend to the manufacturer of maintainer of the aircraft, to those employing the pilot and to the pilot himself.

There is little the pathologist can do under the first heading unless a mechanical defect is clearly shown by autopsy as described in the first lecture. It is possible that the demonstration of carbon monoxide intoxication might disclose a maintenance abnormality; such cases are rare but are dramatic when they occur[5].

The most important feature as to the employers' negligence rests upon the fitness of the pilot. If disease is discovered at autopsy and is considered to have been causative of or contributory to the accident, it may well be that the employers are responsible but there is no strict liability; there will be no negligence if the illness could not have been diagnosed or otherwise foreseen. It follows that very considerable importance will be attached to the extent and efficacy of pre-flight medical selection and much of this will be correlated with the more subtle post-mortem findings. A good case is thereby made out for the full examination of, say, all killed pilots' hearts; only in this way can the specificity and sensitivity of the electrocardiogram in asymptomatic persons be assessed.

Alcohol has not been found to be a problem in commercial aviation but is very considerably associated with fatal general aviation accidents. If the pilot is discovered to have been intoxicated, personal negligence, and probably vicarious negligence on the part of the employers, will virtually speak for itself. There are two features of very great practical importance. Firstly, it is imperative that embalming is prohibited until any toxicological investigation has been carried out; attempts to estimate the ante-mortem ethanol value in an enbalmed body are invariably frustrated when it comes to interpretation. Secondly, there is the vexed question of post-mortem production of ethanol by micro organisms. This is capricious in its occurrence[6], but it certainly may arise, particularly if the body has many open wounds. As a consequence, every post-mortem blood alcohol estimation from accident cases should be backed by a urine estimation - in normal circumsances, the urine does not putrify to the same extent as does blood; others have suggested a vitreous humour estimation as corroborative evidence

One unusual feature of the medico legal importance of alcohol deserves mention in passing. Very many people take out personal accident insurance policies for relatively low premiums. Nearly all of these have an alcohol exclusion clause to the effect that benefits are not payable if the subject was intoxicated at the time of death. There

is no causative association stated. It could be, therefore, that insurance companies might probably ask for post-mortem blood alcohol results on passengers where, once again, the same two complications as to interpretation would be of great importance.

Other legal and insurance problems.

The cause of death in persons killed by negligence is of more than academic or investigative interest. In an action for damages, restitution for pain and suffering will almost certainly be sought. The pathologist must, therefore, make some assessment of the agonal period and of the physical conditions during that time.

Fitness is not only a matter of importance in the aircrew; it also has serious conequences as to the assessment of damages for all those killed. The loss of a fit young father is clearly of greater financial significance to the family than is the loss of one with advanced lymphoma. Both the family and the insurers are entitled to the truth and, in many cases, it will only be the pathologist who can provide the necessary data. There is, thus, a very good case to be made out for autopsy in every accidental death irrespective of the total number of bodies. But, at the same time, it behoves the pathologist to be aware of the importance which may be attached to some relatively trivial item in his report. Thus, when concerned with the accident investigation, he may write of a passenger 'severe coronary atheroma' and regard it as of no consequence; but it may acquire very considerable importance in the context of damages payable.

Commorientes

All countries have some laws that deal with the disposal of assets when it appears impossible to decide which of two testatory beneficiaries died first - commonly this is a matter of husband and wife. But whatever rule is applied, the presumption of simultaneous death is rebuttable on the evidence and much of the evidence may be pathological. Moreover, the length of the time one spouse survived the other is immaterial - seconds are as important in law as are weeks. Thus, the subject of commorientes - or 'dying together' - which was once an interesting academic exercise has now become a serious practical problem which is almost specific to aviation; the pathologist cannot shrug off his responsibility in the matter.

Rather subtle ways of establishing that a casualty lived after a crash are available - in particular, the presence of carboxyhaemoglobin after exposure to fire or the formation of pulmonary fat and bone marrow emboli after fracture - but these are of little value in a comparative sense[7]. What is important is the precise cause of death. It is reasonable to suppose that a person who has died from burning in a crash has survived one who was decapitated; even so, in such an example, the possibility of decapitation being a heat induced artefact has to be considered.

Criminality and aircraft accidents

Criminality in aviation is not only of importance in accident investigation. It has further great significance in civil matters in so far as insurance liability passes to the 'war risks' underwriters if the accident can be shown to be due to criminal violence.

Basically, the pathologist's role in criminality refers to illegal passage, hi-jacking and sabotage or deliberate destruction of the aircraft.

The discovery of illegal passage is essentially a matter of identification. There can be no excuse for failure to make any attempt at individual identifiction - but, at the very least, an accurate count of bodies must be obtained.

Hi-jacking can only rarely fail to be diagnosed after an accident as there will have been communication between the criminals and the ground in most cases. Nonetheless, there are times when the unusualness of the accident suggests the possibility of replacement of the pilot, in which case the significant information to be obtained includes:

(a) the discovery of a pattern of injuries in the pilot which is inconsistent with the conditions on the flight deck.

(b) the presence of unusual injuries in the crew.

(c) demonstration of the use of firearms, including the interpretation of any positive findings.

By far the most important aspect, however, is the demonstration of sabotage. This will be strongly suspected if there is technical evidence of unexpected breakup in the air. But many such instances are designed to occur over the sea and, in this case, it may be that only bodies are available for examination; the full onus then rests on the pathologist. The following points should be looked for:

(a) an unexpected scatter of bodies, emphasising the importance of a 'body plot'.

(b) An unusual pattern of injuries, particularly one which divides the casualties into groups of differing severity of injury.

(c) Evidence of anoxia or decompression, including turbulence and rapid descent.

(d) The isolation of a target or 'odd man out'.

(e) The discovery of bomb fragments.

(f) The recovery of fragments and metallurgical examination.

The importance of x-ray examination in the diagnosis of criminality scarcely needs emphasis. If hi-jacking or sabotage be suspected, radiology must be commenced ab initio - all portions of human remains being examined before autopsy. This is expensive but the process can be discontinued once suspicions are allayed[8,9].

## CONCLUSION

The legal implications of the aircraft accident are as important to the pathologist as are the investigative problems. It is, however, to be noted that the process of pathological study is the same in both cases. A thorough autopsy examination will reveal all the necessary answers and, above all, there need be no conflict of interests between the medical advisors to the investigator in charge and the medico legal authorities.

Aircraft accidents are, however, no respectors of nationality. They may occur in countries which have very different laws and customs relating to the disposal of the dead. They may involve casualties from several states, all of whom may have different approaches to the effects of death. Very important issues may depend upon the pathological investigation and much rests on the depth of that investigation - a pathologist who is content with a superficial, external examination of the bodies may, for example, reach a completely different decision as to simultaneous death from one who has performed a full autopsy with histological and toxicological backup. There is, therefore, a great need for an internationally agreed standard of investigation of aviation deaths. The prospect is daunting when confronted with a hundred or more bodies. But Annex 13 to the Convention on International Civil Aviation recommends that a full autopsy be carried out on all fatalities and all advanced countries are signatories of the Convention. If we subscribe to it, we should surely act upon its provisions.

## REFERENCES


1. Mason, J.K. 'The aircraft accident as an example of a major disaster', in 'The Pathology of Violent Injury', ed. J.K. Mason, London: Edward Arnold, 1978, Chap. 4.

2. Stevens, P.J. 'Fatal Civil Aircraft Accidents' Bristol: John Wright & Sons, 1970, Chap. 22.

3. Stevens, P.J. 'Investigation of mass disaster' in 'Modern Trends in Forensic Medicine - 3' ed. A.K. Mant, London: Butterworths, 1973, Chap. 8.

4. Krefft, S. 'Estimation of pilot control at the time of the crash' in 'Aerospace Pathology', eds. J.K. Mason & W.J. Reals, Chicago: College of American Pathologists Foundation, 1973, Chap. 11.

5. Stevens, P.J., ref. 2 above, pp. 31-41.

6. Corry, J.E.L. 'Possible sources of ethanol ante- and post-mortem: its relationship to the biochemistry and the microbiology of decomposition' J Appl Bact 44: 1978, 1 - 56.

7. Buchanan, D. & Mason, J.K. 'Occurrence of pulmonary fat and bone marrow embolism' Amer J Forens Med Path 3: 1982, 73-8.

8. Dille, J.R. & Hasbrook, A.H. 'Injuries due to explosion, decompression and impact of a jet transport' Aerospace Med 37: 1966, 5- 11.

9. Mason, J.K. & Tarlton, S.W. 'Medical investigation of the loss of the Comet 4B aircraft, 1967' Lancet 1: 1969, 431-4.

## SELECTIVE BIBLIOGRAPHY

This Bibliography with Abstracts has been prepared to support AGARD Lecture Series No. 125 by the Scientific and Technical Information Branch of the US National Aeronautics and Space Administration, Washington, D.C., in consultation with the Lecture Series director, Dr B.O.Hartman.

UTTL: The prevalence of visual deficiencies among 1979 general aviation accident airmen

AUTH: A/DILLE, J. R.; B/BOOZE, C. F., JR. PAA: B/(FAA, Civil Aeromedical Institute, Oklahoma City, OK) Aviation, Space, and Environmental Medicine, vol. 53, Feb. 1982, p. 179-182.

ABS: The reported study of 1979 accidents shows that the relatively small number of pilots with aphakia and artificial lens implants, as well as the total eye pathology population, had significantly higher accident rates, but the monocular pilots did not. There are questions about the functional importance of 20/30 and 20/40 best corrected visual acuity in one case, and entry of 'no fusion' in another, and the dynamic, peripheral, depth and accommodative performance of several with appreciable pathology who have a corrected central acuity of 20/20. It is recommended to continue investigations of the considered type. The obtained findings should be taken into account in the design of research on contemporary problems in aviation medicine. Meanwhile, continuing emphasis must be placed on the accurate measurement of visual functions required for medical certification in communications with FAA aviation medical examiners. 82/02/00 82A21689

UTTL: Forensic dentistry

AUTH: A/MORLANG, W. M. PAA: A/(USAF Hospital, New York, NY) Aviation, Space, and Environmental Medicine, vol. 53, Jan. 1982, p. 27-34.

ABS: The specialty of forensic dentistry is examined and its role in the multidisciplinary investigation of the identity of aircraft accident fatalities is addressed. State-of-the-art techniques are discussed including professional procedures and organization, radiology, documentation, and data automation. A unique procedure for courtroom presentation of identification confirmation dental radiographs is provided. The increased utilization of forensic dentistry within aviation pathology is encouraged. 82/01/00 82A18737

UTTL: Hepato-splenic injury in aircraft accidents

AUTH: A/HILL, I. R. PAA: A/(Wegberg Militaerkrankenhaus, Moenchengladbach, West Germany) (Joint Committee on Aviation Pathology, Scientific Session, 12th, Halton, Bucks., England, Oct. 14-16, 1980.) Aviation, Space, and Environmental Medicine, vol. 53, Jan. 1982, p. 19-23.

ABS: The incidence of hepato-splenic injury is greater in fatally injured victims than it is in survivors, though there is some variation in the literature. In fatal aircraft accidents, hepatic injury is more common than is splenic injury. There is a direct association with damage to the lower chest and injury to these organs. Injury scoring is a good mathematical tool for studying the severity of injuries in aircraft accidents, and gives an indication of the severity of injury in relation to the intensity of impact. 82/01/00 82A18735

UTTL: Liver pathology in aircrew

AUTH: A/UNDERWOOD GROUND, K. E. PAA: A/(RAF, Institute of Pathology and Tropical Medicine, Halton, Bucks., England) (Joint Committee on Aviation Pathology, Scientific Session, 12th, Halton, Bucks., England, Oct. 14-16, 1980.) Aviation, Space, and Environmental Medicine, vol. 53, Jan. 1982, p. 14-18.

ABS: The aim of this review is to determine the incidence and aetiology of fatty liver and other liver pathology in aircrew. A review of 525 fatal aircraft accidents resulted in deaths of 776 aircrew. Histology of liver, available in 423 aircrew, was reviewed and 118 found abnormal. There were 66 cases (15.6%) of fatty livers. In 11 of the fatty livers and 8 of the 52 non-fatty livers there was histopathologic evidence compatible with alcohol abuse (4.5%). The histopathologic appearances are discussed. 82/01/00 82A18734

UTTL: Relationships between naval aviation safety and pilot flight experience

AUTH: A/BOROWSKY, M. S. PAA: A/(U.S. Naval Safety Center, Norfolk, VA) Aviation, Space, and Environmental Medicine, vol. 52, Oct. 1981, p. 608-610.

ABS: Flight activity of all aviators flying naval aircraft and aircraft accident data were analyzed to determine if statistical relationships among lifetime and recent experience variables and accident liability exist. The results demonstrate that accident potential, though not statistically related to flight hours in 30-d periods, is correlated with lifetime flight experience with the higher liability associated with minimal amounts of flight hours and with transitioning into new aircraft. 81/10/00 82A11031

UTTL: A histopathological study of coronary arteries in aircrew fatalities during 1962-1978

AUTH: A/ADAVAL, S. K.; B/DIWAN, R. N.; C/VERMA, R. N.; D/KUNZRU, G. N. PAA: A/(Indian Air Force, Institute of Aviation Medicine, Bangalore, India); B/(Air Force Central Medical Establishment, New Delhi, India); C/(Armed Forces Medical College, Poona, India)

Aviation Medicine, vol. 25, June 1981, p. 1-6.

ABS: The incidence of coronary artery disease in aircrew members is evaluated on the basis of a histopathological study of accident fatalities in the period 1962-1978. Coronary artery slides available for 174 aircrew autopsies were examined and compared with those taken from 105 autopsies performed on nonaircrew personnel of the same age groups who had died with no evidence of atherosclerotic conditions. Microscopic disease is found in 29.3% of the aviators, aged 20-39, and 14.3% of the control group, with the incidence of the disease increasing with subject age and accumulated flight hours. A greater incidence is observed in supersonic and transonic pilots despite their lower average age than helicopter and transport pilots, which finding is attributed to the stress factors inherent in high-speed aviation. Of the three cases of aircrew with severe atherosclerotic conditions, only one is found to be possibly related to the accident. 81/06/00 81A49951

UTTL: Aerial collisions with relief features
Navigation (Paris), vol. 29, July 1981, p. 288-311. In French.

ABS: An analysis is presented of characteristics common to jet aircraft collisions with obstacles on the ground. Attention is given to the conditions of visibility, flight control responsibilities, knowledge of the terrain by the crew and predicted flight paths as possible factors contributing to collisions during the approach and landing phases of a flight. It is pointed out that such accidents are usually attributed to the lack of a precise determination of aircraft position and a closer cooperation between the flight commander and the other members of the crew in preparation for descent is recommended. The circumstances of two aircraft accidents classified as relief collisions are related as illustrations of these points. The accidents involved the collision of a SE 210 Caravelle with a hill upon a direct approach to Dubai airport in March, 1972, and the destruction of a B 727 upon approach to Washington Dulles International Airport in December, 1974. 81/07/00 81A44323

UTTL: A contribution to the causal study of air accidents - A method for testing for medicinal substances in biologic samples

AUTH: A/DELCROIX, J. P.; B/PICART, P. E. PAA: B/(Centre d'Etudes et de Recherches de Medecine Aerospatiale, Paris, France) Medecine Aeronautique et Spatiale, Medecine Subaquatique et Hyperbare, vol. 20, 1st Quarter, 1981, p. 36-39. In French.

ABS: A review is presented of detection methods currently used to find and identify medicinal substances in biological samples from flight personnel, noting the necessity of extending the range from narcotics to alcohol and carboxyhemoglobin. Because certain tissue samples are difficult to obtain preflight and impossible to acquire post accident, especially for combat pilots, blood and sanguinous fluids, including saliva, are chosen as the best preflight samples. Centrifugation or dehydration followed by organic solvent purification using 2 to 5 ml of blood or other bodily liquid is considered sufficient for discovering neutralized, acid, and weakly or strongly basic drugs. Chromatography of extracts allows detection down to 100 ng levels, spectrometry allows detection of substances with a low molecular weight, and mass spectrometry in conjunction with chromatography of solids yields absolute identification down to 10 pg, using ionized fragments in a magnetic field at 1/10,000 torr. An example is provided for detection of caffeine in the blood of an air accident victim. 81/03/00 81A39681

UTTL: The effects of tobacco on aviation safety

AUTH: A/DILLE, J. R.; B/LINDER, M. K. PAA: B/(FAA, Civil Aeromedical Institute, Oklahoma City, Okla.) Aviation, Space, and Environmental Medicine, vol. 52, Feb. 1981, p. 112-115.

ABS: In 1976, the Federal Aviation Administration was petitioned to issue regulations that would prohibit all smoking in the cockpit during commercial flight operations and prohibit preflight smoking by flight crewmembers within 8 h before commercial flight operations. A review of the literature was conducted to determine the effects on pilot performance of carbon monoxide (CO), nicotine, and smoking withdrawal. The records of 2,660 fatal general aviation aircraft accidents in 1973-1976 have been examined. Smoking was not identified as a causal factor but may have contributed to the cause of some of these accidents. However, the compound factors that were often found and the dire consequences are far less likely to occur in air commerce operations. For some, withdrawal symptoms may occur and more than offset any benefits to aviation safety that are claimed for a ban on preflight and in-flight smoking. 81/02/00 81A23396

UTTL: Postmortem coronary atherosclerosis findings in general aviation accident pilot fatalities - 1975-77

AUTH: A/BOOZE, C. F.; B/PIDKOWICZ, J. K.; C/DAVIS, A. W.; D/BOLDING, F. A. PAA: D/(FAA, Civil Aeromedical Institute, Oklahoma City, Okla.) Aviation, Space, and Environmental Medicine, vol. 52, Jan. 1981, p. 24-27.

ABS: The autopsies of 764 pilots involved in fatal general aviation accidents during the years 1976-77 were reviewed to appraise the age specific prevalence of coronary atherosclerosis among the autopsied group. Of the pilots killed in aircraft accidents and autopsied during 1975-77, 51% were found to have some degree of coronary atherosclerosis ranging from minimal to severe. However, only about 5% of the autopsied group were categorized as having severe coronary atherosclerosis. The rate per 1,000 of severe coronary atherosclerosis increased with age from 14.5 for ages less than 30, to 89.9 for ages 50 years and above; the rate nearly tripled from ages 30-39 to 40-49 (22.1 to 63.6). The prevalence of coronary atherosclerosis among this group of autopsied airmen is less than would have been expected based on the results of other recent studies. 81/01/00 81A22109

UTTL: The apparent ignoring of pilot fatigue by the NTSB in airline crashes

AUTH: A/PRICE, W. J. PAA: A/(United Air Lines, Inc., Redwood City, Calif.) In: Survival and Flight Equipment Association, Annual Symposium, 17th, Las Vegas, Nev., December 2-6, 1979, Proceedings. (A81-22076 08-03) Canoga Park, Calif., Survival and Flight Equipment Association, 1980, p. 241-247.

ABS: The trip sequence of a United Airlines DC-8 freighter which crashed near Kaysville, Utah on Dec. 18, 1977 is examined. A model demonstrating how fatigue could have been a contributing factor in the accident is presented with a view toward sleep disruption, circadian desynchronosis and sleep reversal. The symptoms attending sleep loss and desynchronosis include short term memory loss, forgetfulness, inattention to detail, relaxation of personal standards and irritability. In normal human circadian rhythm, the zenith should occur between the 1500 to 1700 home domicile. It is noted that of the 81 human factor items outlined by the National Transportation Safety Board for accident investigation, not one pertains to pilot fatigue. 80/00/00 81A22104

UTTL: Delayed ejection

AUTH: A/SHANNON, R. H. PAA: A/(Talley Industries, Inc., Highland, Calif.) In: Survival and Flight Equipment Association, Annual Symposium, 17th, Las Vegas, Nev., December 2-6, 1979, Proceedings. (A81-22076 08-03) Canoga Park, Calif., Survival and Flight Equipment Association, 1980, p. 219-221.

ABS: The decision factor, that is, the aspect of pilot escape that depends on the actions of the pilot, is discussed. It is noted that the decision to eject is often delayed until it is too late and that despite system refinements and training programs, the problem persists. It is pointed out that the crewman often fails to recognize that he has reached a point of no return. It is felt that a device is needed to give the pilot information regarding the minimum height at which escape action may be taken. 80/00/00 81A22102

UTTL: The evaluation of aircraft collision probabilities at intersecting air routes

AUTH: A/HSU, D. A. PAA: A/(Wisconsin, University, Milwaukee, Wis.) Journal of Navigation, vol. 34, Jan. 1981, p. 78-102. U.S. Department of Transportation

ABS: Formulas useful for the calculation of aircraft mid-air collision probabilities at intersecting air routes are developed. The aircraft overlap density, a key parameter in the calculation, is expressed as a function of the intersection angle of air routes, aircraft speeds, the nominal separation, and parameters in the position-error distribution. Two representative probability models for position errors are used to illustrate the computational procedures suggested. A method of approximation over large navigation systems is also proposed. 81/01/00 81A21967

UTTL: Air traffic control problems - A pilot's view

AUTH: A/FOWLER, F. D. PAA: A/(Fowler, Fuehrer and Associates, Orlando, Fla.) Human Factors, vol. 22, Dec. 1980, p. 645-653.

ABS: Specific examples of crashes and near midair collisions are used to identify existing and potential human error sources. System-induced human errors caused by radar and information-processing limitations, inadequate communication capabilities, and Federal Aviation Administration policy decisions are discussed. An overall reconsideration of human error analysis and prevention is proposed. 80/12/00 81A20914

UTTL: Mobilization of trauma teams for aircraft disasters

AUTH: A/STAR, L. D.; B/ABELSON, L. C.; C/DELGUERCIO, L. R. M.; D/PRITCHETT, C. PAA: D/(John F. Kennedy International Airport, Medical Office, Jamaica, N.Y.) Aviation, Space, and Environmental Medicine, vol. 51, Nov. 1980, p. 1262-1266.

ABS: With more survivors of air crashes involving jumbo jets, an improved plan for life-saving emergency care at the crash site is discussed. The concept of airlifting predesignated Trauma Teams to the crash site from large medical centers within a radius of 100 miles is discussed. The 'work-shop' for these teams is described in detail, providing an operating and intensive care facility at the scene of the disaster. It is shown how this kind of planning can be applied to natural disasters with multiple casualties as well as to airport disasters. 80/11/00 81A13514

UTTL: Developing an emergency medical disaster plan for an airport

AUTH: A/PIXLEY, J. I. PAA: A/(Minneapolis-St. Paul International Airport, Minneapolis, Minn.) Aviation, Space, and Environmental Medicine, vol. 51, Nov. 1980, p. 1258, 1259.

ABS: The development of the emergency medical disaster plan for Minneapolis-St. Paul International Airport as a model for other major hub airports is discussed. Conformance with federal regulations and the need to closely coordinate activities with both on-airport personnel and off-airport facilities are considered and incorporated into the plan. Manpower sources are reviewed and methods are developed for the efficient handling and treatment of disaster victims. Essential services for an emergency are categorized and their responsibilities designated. Centers of control for support personnel and vehicles are established. Consideration is also given to the special requirements of friends and relatives of the victims and of the news media. Conducting disaster drills as a means to evaluate and improve the basic plan is also examined. 80/11/00 81A13513

UTTL: Medical coordination in airport disasters

AUTH: A/WEBB, A. C. PAA: A/(Airport Medical Clinic, Minneapolis, Minn.) Aviation, Space, and Environmental Medicine, vol. 51, Nov. 1980, p. 1256-1258.

ABS: The goals of an airport disaster plan include the care, treatment and transportation of the wounded with the quality and quantity of care that minimizes the mortality and morbidity of the survivors of a crash. Coordination of the medical aspects of these plans requires participation by physicians, nurses, ambulance and hospital personnel, psychologists, and psychiatrists. To maintain these diverse groups in a state of readiness for a potential disaster which may have a frequency of 5-20 years is a challenging problem. This paper addresses methods of accomplishing this goal. 80/11/00 81A13512

UTTL: Structural integrity - The accident investigator's view

AUTH: A/FELTHAM, R. G.; B/SMART, K. P. R. PAA: B/(Department of Trade, London, England) In: Long-life aircraft structures; Proceedings of the Spring Convention, London, England, May 14, 15, 1980. (A80-50580 22-01) London, Royal Aeronautical Society, 1980, 5 p.

ABS: Analyses of various aircraft are presented from an accident investigator's point of view. Three specific examples are cited: (1) a vanguard aircraft which lost the major part of its tailplanes in flight, (2) an HS748 aircraft that lost the outer portion of its starboard wing in flight, and (3) a Boeing 707 which lost its starboard horizontal stabilizer in flight. The reasons for failure or fatigue on these aircraft are discussed, noting that most problems arose due to inadequate design, inadequate production techniques, and inadequate and superficial inspection procedures. Results indicate that instances of design inadequacy highlight the designer's problems in fully understanding the stress distribution within a complex structure and the difficulties of producing a fatigue test program that accurately represents the conditions met in service. 80/00/00 80A50591

UTTL: A systematic technique for the identification of crash hazards in U.S. Army aircraft

AUTH: A/HICKS, J. E.; B/ADAMS, B. H. PAA: B/(U.S. Army, Safety Center, Fort Rucker, Ala.) (Joint Committee on Aviation Pathology, Scientific Session, 11th, Annapolis, Md., Sept. 5-8, 1978.). Aviation, Space, and Environmental Medicine, vol. 51, Sept. 1980, p. 1043-1049.

ABS: A methodology for identification of crashworthiness deficiencies in Army aircraft is discussed. The methodology provides for injury and impact data to be extracted from accident reports using a specially-developed injury coding system. Personnel injuries are costed through a technique which provides for consideration of each injury based on its relative severity as determined by medical examination. Crash injury causes are identified and ranked according to

the magnitude of their effect and probability of occurrence. The technique is designed to provide recommendations as to the most urgent crashworthiness research/development/procurement efforts for consideration by aircraft systems managers and aviation research laboratories. An application of the methodology to an operational Army aircraft is shown. Results typically available are discussed. Recommendations are made as to the use of the methodology and to additional investigation aids which would improve the future identification of crash hazards. 80/09/00 80A50113

UTTL: Role of radiology in aviation accident investigation
AUTH: A/LICHTENSTEIN, J. E.; B/MADEWELL, J. E.; C/MCMEEKIN, R. R.; D/FEIGIN, D. S.; E/WOLCOTT, J. H. PAA: E/(U.S. Armed Forces Institute of Pathology, Washington, D.C.) (Joint Committee on Aviation Pathology, Scientific Session, 11th, Annapolis, Md., Sept. 5-8, 1978.) Aviation, Space, and Environmental Medicine, vol. 51, Sept. 1980, p. 1004-1014.
ABS: Radiographic screening of fatality victims for skeletal detail, dental and surgical artifacts, personal effects, and foreign bodies is of established value. Radiography as the primary means of positive victim identification, through comparison with antemortem films and records, is an important new role. Data on sources of injury and relationships between victims and the crash environment may be derived from radiographic injury patterns and may be correlated with mechanisms of injury production. The result of such analysis is improved safety design. Such radiography poses unique technical and logistical problems, often involving temporary or remote facilities, which must be solved with consideration for privacy and safety. Advance planning is essential for maximum benefit from radiographic investigation. 80/09/00 80A50107

UTTL: Investigation of life change as a contributing factor in aircraft accidents - A prospectus
AUTH: A/HAAKONSON, N. H. PAA: A/(Department of National Defence, Directorate of Preventive Medicine, Ottawa, Canada) (Joint Committee on Aviation Pathology, Scientific Session, 11th, Annapolis, Md., Sept. 5-8, 1978.) Aviation, Space, and Environmental Medicine, vol. 51, Sept. 1980, p. 981-988.
ABS: A personal perspective on attempts to reduce aircraft accidents resulting from human failure in the cockpit is presented. The premise is that accidents result from an imbalance between performance ability and performance demand. Advances in decreasing pilot-induced accidents must come from methods that will prevent the stresses that diminish performance ability. It is suggested that the investigation of life change as a contributing factor in aircraft accidents will be fruitful because of the tremendous amount of research that has already been done in this field. A review of previous work leads to three recommendations: the Recent Life Change Questionnaire (RLCQ) should be developed as a tool for management and individual aircrew; a character assurance program should be adopted; and a technique to remove accident-prone individuals should be developed. 80/09/00 80A50104

UTTL: Some aspects of the introduction of a directive requiring the reporting, investigation, and analysis of flight incidents in civil aviation
AUTH: A/KAUFMANN, B. PAA: A/(Staatliche Luftfahrtinspektion, Berlin, East Germany) Technisch-oekonomische Information der zivilen Luftfahrt, vol. 16, no. 1, 1980, p. 8-12. In German.
ABS: Some of the major aspects of the Decree of October 1, 1979, requiring a full investigation of any accident, near-accident, or unforeseen flight development in civil aviation are examined. Some responsibility specifications and guidelines for conducting investigations and data analysis are discussed. 80/00/00 80A47778

UTTL: The analysis of incidents
AUTH: A/MEIKLEM, P.; B/RUBEN, H. D. PAA: B/(Civil Aviation Authority, London, England) Voies-Aviation Civile, no. 7, Supplement, Spring 1980, p. 70-72. In French.
ABS: The principles of aircraft incident investigation are examined, with particular reference to the tasks of the Civil Aviation Authority of the United Kingdom. Consideration is given to techniques for collecting information on incidents, with emphasis on the use of flight recorders. 80/05/00 80A39597

UTTL: The place of the psychological factor among the causes of aircraft accidents in general aviation
AUTH: A/DIGO, R. J.; B/LAVERNHE, J. PAA: A/(Centre Principal d'Expertise Medicale du Personnel Navigant, Paris, France); B/(Compagnie Nationale Air France, Centre d'Examen Medical du Personnel Navigant, Paris, France) Medecine Aeronautique et Spatiale, Medecine Subaquatique et Hyperbare, vol. 18, 1st Quarter, 1979, p. 45-51. In French.

ABS: The significance of psychological factors as causes of general aviation aircraft accidents is discussed. The qualitative deficiencies of the medical examination of general aviation pilots and the unique psychological character of general aviation are pointed out, and the causes of aircraft accidents are classified as extrinsic (meteorological, technical, or infrastructural) or intrinsic human factors, which are further subdivided into human technical failures, somatic failures, psychosomatic failures, psychological failures, moral failures, and human relations failures. The various psychopathological traits encountered in general aviation are then examined, including age-related disorders, neuroses, psychosomatic disorders, psychotic states, psychopathic personalities and bio-neuro-organic states including intoxication. Finally, a set of measures intended to reduce the incidence of psychologically caused aircraft accidents is proposed. 79/03/00 80A32583

UTTL: The organization of medical aid in air disasters - Berlin-Tegel international airport

AUTH: A/POYOT, G. PAA: A/(Armee de l'Air, Base Aerienne, Ocney, Meurthe-et-Moselle, France) Medecine Aeronautique et Spatiale, Medecine Subaquatique et Hyperbare, vol. 18, 1st Quarter, 1979, p. 36-39. In French.

ABS: Consideration is given to the provisions for medical aid in the event of a major passenger aircraft crash at the Berlin-Tegel international airport. The emergency medical plan consists of the localization of the accident and the broadcasting of the medical and fire alert, the fighting of any fire and the freeing of victims, medical first aid (triage and the preparation of wounded for evacuation) and the evacuation of wounded to the receiving hospitals. Medical personnel are drawn from the permanent medical staff of the air base having jurisdiction over the airport and from local hospitals, and are equipped with a mobile triage and first aid station capable of handling 75 casualties. Medical strategies include a pretriage to identify and treat the most seriously wounded at the site of the accident, the optimal placement of the triage center, and the utilization of specialized equipment packages designed for the treatment of the most common aircraft accident injuries. The plan requires the supervision of the chief airport physician from the time of the first alert to the evacuation of the wounded, and close cooperation between the health services of the base. 79/03/00 80A32581

UTTL: The contribution of histopathology to investigations following aircraft accidents

AUTH: A/NOGUES, C. Medecine Aeronautique et Spatiale, Medecine Subaquatique et Hyperbare, vol. 18, 1st Quarter, 1979, p. 24-30. In French.

ABS: The histopathological examination of tissue samples obtained in the investigation of aircraft accidents is discussed. Information obtainable from studies of hepatic, pulmonary, renal and visceral lesions and tissue debris is illustrated, and the classification of lesions into those caused by the accident, those of apparently questionable significance (possible relating to pre-existing conditions), those contributing to the reconstruction of the events of the accident and those not relating to the cause of the accident is considered. It is concluded that, although histopathological analysis rarely leads to the proof of the cause of an aircraft accident, it can provide information as to the sequence of events occurring during the accident and pre-existing conditions leading to the aggravation of dangerous circumstances. 79/03/00 80A32579

UTTL: Evidence in aircraft accident investigation and its evaluation

AUTH: A/MUKHERJEE, S. K. PAA: A/(Indian Air Force, Medical Services, New Delhi, India) Aviation Medicine, vol. 23, Dec. 1979, p. 125-128.

ABS: The paper briefly outlines three of the numerous aircraft accidents which would have passed as 'Cause undetermined' but for the contribution of experts in the field of aviation medicine. There are three basic sources of evidence in an aircraft accident: (1) information from persons having knowledge of the accident; these persons are the crew, passengers, eyewitnesses and air traffic controllers; (2) wreckage, scene of the accident, and records and documents pertaining to the aircraft, aircrew, weather, and flight, as well as ATC records; and (3) persons who know the environment and the pilot. Attention is given to examination of wreckage and the scene of accident, examination of witnesses, and evaluation of evidence. The testimony should be evaluated in terms of realities of the situation. Examination of aircrew is the most sensitive part of the investigation and the investigators must be extremely tactful to elicit correct evidence. 79/12/00 80A31593

UTTL: Psycho-social aspects of aircraft accidents
AUTH: A/KUMAR, V. PAA: A/(AFCME, New Delhi, India) Aviation Medicine, vol. 23, Dec. 1979, p. 115-118.
ABS: The cause of human error in an aircraft accident can be determined by investigating the psychosocial aspects of the individual responsible for the accident. The paper discusses psychosocial factors relative to attention, emotional stability, motivation, experience, skill, self-esteem, fatigue, psychological stress and aircraft pilot, accident proneness, attitudes and flying, habit interference, crew behavior, man in a group, alcohol aftereffects and flying, as well as maintenance crew and air traffic control staff. Recommendations are made for reliably determining the cause of human error in an aircraft accident and for making psychosocial studies very meaningful. 79/12/00 80A31591

UTTL: An analysis of autopsy investigations at IAM /1962-76/
AUTH: A/ADAVAL, S. K.; B/GANDHI, G. S.; C/KUNZRU, G. N. PAA: A/(Indian Air Force, Institute of Aviation Medicine, Bangalore, India); B/(ABEU, Bangalore, India) Aviation Medicine, vol. 23, Dec. 1979, p. 96-102.
ABS: The paper presents the results of a study of 270 autopsy reports of air crash fatalities for the period 1962-1976. The factors are correlated with factors such as the age of the deceased, aircraft types, phases of flight, survival, autopsy system, cause/mode of death and injuries to skeletal/visceral systems. A comparison is made with the findings of other workers in the field. Finally, attention is given to inconsistencies in the correlation of autopsy findings with crash factors. 79/12/00 80A31587

UTTL: An investigation of landing accidents in relation to fatigue
AUTH: A/HILL, A. B.; B/WILLIAMS, G. O. In: Aircrew stress in wartime operations. (A80-23206 08 53) London and New York, Academic Press, 1979, p. 89-108.
ABS: The effects of fatigue on pilot landing performance are investigated for the case of bomber pilots returning after sorties of different durations. Statistics on accidents occurring during landings which were not forced or due to enemy action, recorded from April 1940 to March 1942 at RAF Bomber Command after night operations of one to ten hours, were compared. A rather high accident rate is found for sorties of under two hours or greater than 10 hours, most likely due to the difficulties leading to the recall or return of the aircraft in the former case and pilot fatigue in the latter. Within the relatively long interval of two to ten hours, within which most flights were made, there is no evidence of increasing pilot fatigue having lead to increased landing accident rates, indicating that pilots have managed to overcome the effects of the fatigue observed in laboratory experiments sufficiently to avert reportable landing accidents. 79/00/00 80A23214

UTTL: Human factors in aircraft accidents
AUTH: A/SHANNON, R. H.; B/ALKOV, R. A. Approach, vol. 25, Dec. 1979, p. 18-21.
ABS: The main purpose of the work is to examine the human errors that are involved in aircraft accidents, emphasizing pilots and other personnel as the primary accident causes. Some of the physiological, psychological and psychosocial limitations and strengths of human beings are examined. It is concluded that the realization of our human error rates may not significantly improve while the cost per mishap will consistently increase and that a more innovative program will be necessary for future improvements. 79/12/00 80A21970

UTTL: The 1976 accident experience of civilian pilots with static physical defects
AUTH: A/DILLE, J. R.; B/BOOZE, C. F. PAA: B/(FAA, Civil Aeromedical Institute, Oklahoma City, Okla.) Aviation, Space, and Environmental Medicine, vol. 51, Feb. 1980, p. 182-184
ABS: The paper reports on aircraft accident experience of civilian pilots with physical defects in 1976. It was found that pilots with blindness in either eye or absence of either eye, deficient color vision with a waiver, and deficient distant vision had significantly more accidents than were expected on the basis of observed-to-expected ratios. The accident rates were calculated in 1975, and the rates for airmen with blindness in one eye or absence of an eye were found to be significant; the observed-to-expected ratios for 1976 were 1.91 for deficient color vision with a waiver, 1.28 for contact lens users, 1.37 for blindness in- or absence of either eye, and 1.62 for deficient distant vision. Finally, it was shown that the accident rates per 100,000 h of cumulative and last 6 months flying experience were significantly greater for contact lens users and monocular pilots than for the active airman population. 80/02/00 80A21552

UTTL: Current role of alcohol as a factor in civil aircraft accidents

AUTH: A/RYAN, L. C.; B/MOHLER, S. R. PAA: A/(FAA, Office of Aviation Medicine, Washington, D.C.); B/(Wright State University, Dayton, Ohio) (Aerospace Medical Association, Annual Meeting, New Orleans, La., May 8-11, 1978.) Aviation, Space, and Environmental Medicine, vol. 50, Mar. 1979, p. 275-279.

ABS: Ethyl alcohol continues as a serious adverse factor in general aviation flight safety. According to FAA figures, the level of alcohol-associated general aviation fatal accidents has remained relatively static at a 16% general level since 1969. A recent survey of the attitudes of pilots toward alcohol and flying reveals a lack of appreciation among one-third of the pilots concerning the adverse effects of alcohol on safe flight. A renewed pilot education program on alcohol and flight safety appears indicated. 79/03/00 79A27561

UTTL: The use of aviation pathology and aviation medicine as proof of liability and damage

AUTH: A/REALS, W. J.; B/REALS, J. F. PAA: A/(Kansas, University, Wichita, Kan.) (Annual Air Law Symposium, 12th, Dallas, Tex., Apr. 20-22, 1978.) Journal of Air Law and Commerce, vol. 44, no. 2, 1978, p. 297-320.

ABS: Reasons for performing a medical and pathological investigation of an aviation accident are discussed, and some areas of concern to aviation pathologists are examined. Environmental factors are considered with reference to altitude and hypoxia, toxins, and alcohol. Procedures for studying the causes and nature of trauma and the possibility of pre-existing disease are surveyed. 78/00/00 79A22704

UTTL: Physiological biorhythm as a correlate of pilot error accidents and incidents

AUTH: A/HENDRICK, H. W.; B/JONES, H. E. PAA: B/(Southern California, University, Los Angeles, Calif.) In: Human Factors Society, Annual Meeting, 22nd, Detroit, Mich., October 16-19, 1978, Proceedings. (A79-18201 05-54) Santa Monica, Calif., Human Factors Society, Inc., 1978, p. 498-501.

ABS: Aircraft accidents and incidents attributed to pilot error were hypothesized to have occurred while the pilot was in a critical phase for one or more biorhythms. From screening accident and incident reports for a large military unit, two groups of 25 pilots who had been involved in pilot error accidents and one group of 50 pilots who had been involved in pilot error incidents were identified. 13 of the accident validation group and 12 of the cross validation group were found to have been in a critical physiological phase at the time of accident, or twice the number expected by chance. For the incident group, 20 of the 50 pilots were in a critical physiological phase at the time of incident. Results for all three groups exceeded chance at the .025 level. Results for emotional and intellectual biorhythms, and for double critical phases were found not significant. 78/00/00 79A18228

UTTL: An economical approach to an accident information retrieval system /AIRS/

AUTH: A/BURROWS, L. T. PAA: A/(U.S. Army, Applied Technology Laboratory, Fort Eustis, Va.) In: SAFE Association, Annual Symposium, 15th, Las Vegas, Nev., December 5-8, 1977, Proceedings. (A79-14401 03-03) Canoga Park, Calif., SAFE Association, 1977, p. 127-130.

ABS: Aircraft accident prevention and design for crashworthiness would be enhanced by a better knowledge of the accident causes and crash impact forces. Accordingly, the Army established a program for the definition of an economical Accident Information Retrieval System (AIRS) that would record flight and crash impact data. Hamilton-Standard performed the design under contract. The AIRS resulting from this program embodies advanced electronic technology and has an installed weight and cost of approximately 15 pounds and $10,000. This represents a significant step towards the realization of a compact low cost system that could have application to civil aircraft as well as military helicopters and fighters. 77/00/00 79A14419

UTTL: False hypothesis and the pilot

AUTH: A/BURGIN, R. E. PAA: A/(National Transportation Safety Board, Washington, D.C.) Society of Automotive Engineers, Air Transportation Meeting, Boston, Mass., May 1-4, 1978, 7 p.

ABS: The false hypothesis phenomenon is significant in most cause factors assigned to aircraft accidents, including decision making errors, faults in judgment, inattention, and situation avoidance. Situations that support the maintenance of a false hypothesis are identified as high expectancy, reduced anxiety, divided attention, and periods following a high concentration. False hypothesis accidents may be reduced by recognizing the limitations of information processing, studying changes in pilot priorities, and examining previous accidents.

RPT#: SAE PAPER 780528 78/05/00 79A10399

UTTL: U.S. fatal general aviation accidents due to cardiovascular incapacitation: 1974-75

AUTH: A/MOHLER, S. R.: B/BOOZE, C. F. PAA: A/(FAA, Aeromedical Applications Div., Washington, D.C.); B/(FAA, Civil Aeromedical Institute, Oklahoma City, Okla.) Aviation, Space, and Environmental Medicine, vol. 49, Oct. 1978, p. 1225-1228.

ABS: National Transportation Safety Board records for the 1974-75 period indicate that 13 general aviation fatal accidents resulted from cardiovascular incapacitation, with an average of about six per year. The paper presents information on these cases, explores the implications, and discusses preventive measures. The pilots were aged in the range 33-68 yr with both a mean and a median of 52. The relatively large number of pilots in the 50-59 yr age bracket (7 of the 13 cases) is consistent with the chronic nature of the pathogenesis of atherosclerotic coronary heart disease. Since these 13 inflight cardiovascular incapacitations constitutes 0.93% of the total of 1404 fatal general aviation accidents in the 1974-75 period, extensive additional cardiovascular screening procedures are not justified at present on cost/yield basis. 78/10/00 78A52644

UTTL: Spatial disorientation in general aviation accidents

AUTH: A/KIRKHAM, W. R.: B/COLLINS, W. E.: C/GRAPE, P. M.: D/SIMPSON, J. M.: E/WALLACE, T. F. PAA: E/(FAA, Civil Aeromedical Institute, Oklahoma City, Okla.) Aviation, Space, and Environmental Medicine, vol. 49, Sept. 1978, p. 1080-1086.

ABS: Spatial disorientation (pilot vertigo) in aviation refers to the incorrect self-appraisal of the attitude or motion of the pilot and his plane with respect to the earth. The paper documents the occurrence of spatial disorientation in civil aviation accidents and defines the conditions in which spatial disorientation occurs, as revealed by accident statistics. When spatial disorientation is associated with an accident, it is fatal 90% of the time. If external visual cues for proper orientation are missing, as at night or in adverse weather, the pilot may inadvertently maneuver the aircraft violently, thereby overstressing it, or lose control of the aircraft and crash. The material presented is expected to be helpful in educating general aviation pilots about this hazard to flight safety. 78/09/00 78A48081

UTTL: Disorientation training in FAA-certificated flight and ground schools - A survey

AUTH: A/COLLINS, W. E.: B/HASBROOK, A. H.: C/LENNON, A. O.: D/GAY, D. J. PAA: D/(FAA, Civil Aeromedical Institute, Oklahoma City, Okla.) Aviation, Space, and Environmental Medicine, vol. 49, Aug. 1978, p. 947-951.

ABS: A 10-item, voluntary questionnaire answered by 674 flight and ground schools provided information on (1) the conduct of formal instruction about disorientation, (2) the occurrence and content of lectures on disorientation, (3) use of on-the-ground demonstrations of disorientation, (4) use of in-the-air demonstrations of disorientation, (5) use of films on pilot vertigo, (6) amount of instrument flying training students receive, (7) amount of instrument flying training required of flight instructors to maintain their proficiency, (8) adequacy of the schools' programs on disorientation training, (9) other comments, and (10) numerical data regarding the number of students beginning and completing various flight and/or ground school courses. More than one-third of the respondents evaluated their disorientation training program as inadequate and defined the inadequacy most often as a lack of appropriate materials, aids, and information. Tabulations of responses to the separate items suggested areas for improvement in disorientation training. Recommendations were made. 78/08/00 78A46406

UTTL: General aviation crash survivability

AUTH: A/SNYDER, R. G. PAA: A/(Michigan, University, Ann Arbor, Mich.) Society of Automotive Engineers, Congress and Exposition, Detroit, Mich., Feb. 27-Mar. 3, 1978. 27 p.

ABS: Statistics indicate that during the past decade (1967-1976) the number of general aviation aircraft involved in an accident is equivalent to at least 38% of the total U.S. production during that period. The paper reviews and illustrates current general aviation aircraft accident experience relative to occupant impact injury and damage indexes, and provides new data relative to current-generation aircraft. Results clearly indicate that when the cabin structure remains relatively intact, the occupant is adequately restrained in an energy-absorbing seat system, the interior structures are designed to distribute loads and absorb energy, and the impact forces imposed on the occupant are within human tolerances, the occupant can survive without serious injury even when the aircraft is destroyed.

RPT#: SAE PAPER 780017 78/02/00 78A33360

UTTL: Clear air turbulence accidents

AUTH: A/BRUNSTEIN, A. I. PAA: A/(National Transportation Safety Board, Washington, D.C.) SAFE Journal, vol. 8, Spring 1978, p. 17-19.

ABS: National Transportation Safety Board air carrier records for 1964-1975 show 68 accidents involving clear air turbulence (CAT). One hundred eighty-four persons were injured and there were thirty-six fatalities. Most aircraft involved were jets and most accidents occurred between 31,000 and 35,000 feet in normal cruise. CAT forecasting was not particularly accurate. The airlines have suffered severe economic penalties, probably in excess of $23,000,000 annually. It is concluded that more accurate and timely CAT forecasts are needed; CAT detection systems, airborne and ground-based are needed, and real-time weather data are required on the ground and particularly in the cockpit. 78/05/00 78A28833

UTTL: Human factors considerations in establishing aircraft collision avoidance system alert thresholds

AUTH: A/MCFARLAND, A. L. PAA: A/(Mitre Corp., McLean, Va.) SAFE Journal, vol. 8, Spring 1978, p. 9-13.

ABS: This paper discusses considerations that bear on the effectiveness of the pilot's use of collision avoidance alerts. The paper suggests that the human factors involved in the operational use of a collision avoidance system are as important in establishing alert thresholds as are the purely mathematical measures of false alert rate and late alert or missed alert rates. Collision avoidance commands are expected to occur infrequently. Consequently, the pilot's success in using his collision avoidance equipment to avoid a hazardous mid-air encounter depends upon his performance in a moment of surprise, and upon the attitude that he has developed toward this equipment prior to the time of the alert. The difficulties of assessing the human factors of collision avoidance systems under realistic conditions are discussed. Data from past experiments with collision avoidance systems, and operational experience with stall warning devices and the ground proximity warning system are reviewed. The advantages of conducting an operational flight test evaluation of a collision avoidance system before committing that system to implementation are discussed. 78/05/00 78A28832

UTTL: 1975 accident experience of civilian pilots with static physical defects

AUTH: A/DILLE, J. R.; B/BOOZE, C. F. PAA: B/(FAA, Civil Aeromedical Institute, Oklahoma City, Okla.) Aviation, Space, and Environmental Medicine, vol. 49, Feb. 1978, p. 422-425.

ABS: The 1975 aircraft accident experience of an active airman population of 763,793 with eight selected static physical defects are examined. The eight categories are blindness or absence of either eye, contact lenses, deficient color vision without restriction, deficient color vision with restriction, deficient distant vision, paraplegia, deafness, and amputations. Accident rates per 100,000 hr of cumulative and recent flight time are computed for three static defect categories (blindness or absence of either eye, deficient distant vision, and deficient color vision) identified as significant by a previous analysis of 1974 accidents. It is shown that the increased accident experience of monocular pilots, which was observed in 1974 and again in 1975, appears to be real after analysis of accident rates and examination of accident reports. Blindness or absence of either eye, use of contact lenses, and color vision defects with no restriction deserve special attention in analyzing the 1976 aircraft accident data. 78/02/00 78A26740

UTTL: Aircrew Performance Enhancement and Error Reduction (APEER) CORP: Federal Aviation Administration, Washington, D.C. CSS: (Office of Systems Engineering Management.)

RPT#: AD-A069708 FAA-EM-79-3TP23 79/02/20 80N74852

UTTL: Incidence and cost of orientation-error accident in regular Army aircraft over a five-year study period: Summary report

AUTH: A/HIXSON, W. C.; B/SPEZIA, E. CORP: Naval Aerospace Medical Research Lab., Pensacola, Fla.

RPT#: AD-A061705 NAMRL-1238 USAARL-77-19 77/09/28 79N75311

UTTL: Air carrier cabin safety: A survey CORP: Federal Aviation Administration, Washington, D.C.

RPT#: AD-A037906 76/12/00 78N76237

UTTL: Correlation of general aviation accidents with the biorhythm theory

AUTH: A/WOLCOTT, J. H.; B/MCMEEKIN, R. R.; C/BURGIN, R. E.; D/YANOWITCH, R. E. CORP: Armed Forces Inst. of Pathology, Washington, D. C.

RPT#: AD-A041769 77/00/00 73N73102

UTTL: Test and evaluation of improved aircrew restraint systems

AUTH: A/SINGLEY, G. T., III CORP: Army Research and Technology Labs., Fort Eustis, Va. CSS: (Applied Technology Lab.)

ABS: US Army aviation accident data shows that a majority of all injuries in attack helicopters could have been avoided if these aircraft had been equipped with crashworthy seat and restraint systems. The compactness of the cockpit and the close proximity of mission equipment to the aircrew in attack and scout helicopters pose serious crash impact hazards. Although not desirable from a crashworthiness standpoint, operational considerations may dictate that mission equipment and structure be located within the occupant's crash impact motion envelope, particularly for his head. The cockpit can be dethalized further when the improved restraint is complemented by padding potential strike surfaces in the cockpit; making contact surfaces frangible; and providing weapon system sights with frangibility, telescoping, and/or swing-away features. This report presents the results of an effort to test and compare the potential of several aircrew restraint systems to reduce the crash impact motion envelope of helicopter aircrewmen.

RPT#: AD-A107576 USAAVRADCOM-TR-81-D-27 81/09/00 82N16056

UTTL: The prevalence of visual deficiencies among 1979 general aviation accident airmen

AUTH: A/DILLE, J. R.; B/BOOZE, C. F., JR. CORP: Federal Aviation Administration, Oklahoma City, Okla. CSS: (Civil Aeromedical Inst.)

ABS: Analyses of the accident experience of pilots who were monocular, did not meet (even the liberal) vision standards, had color vision defects and no operational restrictions, or wore contact lenses, have shown higher-than-expected accident experience in previous studies. However, no causal role had been assigned by accident investigators and reexamination of the records failed to show any obvious pattern or relationship between the defects and the accidents. In the present study of 1979 accidents, the relatively small number of pilots with aphakia and artificial lens implants, as well as the total eye pathology population, had significantly higher accident rates, but the monocular pilots did not. Again, no causal role had been ascribed. Some associations are debatable, but there is no clear recurring problem. There are still unresolved questions about the consistent operational performance of monocular pilots, those who are not fully corrected to 20/20 distant visual acuity bilaterally, airmen with near vision deficiencies only who are not required to wear corrective glasses, those without fusion, and several with appreciable pathology who have 20/20 corrected central visual acuity but about whom we know very little concerning their dynamic, peripheral, depth or accommodative function.

RPT#: AD-A106489 FAA-AM-81-14 81/07/00 82N16054

UTTL: Improving the crashworthiness of general aviation aircraft by crash injury investigations

AUTH: A/KIRKHAM, W. R. CORP: Civil Aeromedical Inst., Oklahoma City, Okla.

ABS: An accident investigative research program has correlated injuries to aircraft occupants with the accident severity and structural changes in the crash. Findings brought to the attention of aircraft manufacturers have led to specific aircraft being made more crashworthy. Following the finding of a failure in a shoulder harness attachment the manufacturer strengthened the attachment brace. The way a shoulder harness was joined to a lapbelt was modified as a followup to failure of the attachment in an accident. Noted fractures of lapbelt and shoulder harness cable tiedowns led to the use of stronger cables and modification of the installation. Other accident findings resulted in a shoulder strap guide being placed on an inertia reel and a side-mounted seat being modified.

RPT#: AD-A103316 FAA-AM-81-10 81/05/00 81N33174

UTTL: Definition of investigative areas for human-factor aspects of aircraft accidents

AUTH: A/FINEBERG, M.; B/WOELFEL, J.; C/ELY, R.; D/SMITH, M. CORP: BDM Corp., McLean, Va.

ABS: This paper is the final report of a 9-month survey effort designed to identify the major pilot factors involved in aircraft mishaps, rank order the major pilot factors in relation to a return-on-investment metric, identify aviation technologies with a high potential for diagnosing and/or reducing these pilot factors, and suggest potentially high-payoff programs for researching the pilot factor aspects of aircraft for the purpose of reducing their incidence.

RPT#: AD-A101601 BDM/W-79-733-TR SAM-TR-80-48 80/12/00 81N30102

UTTL: Visual illusions as a probable cause of aircraft accidents

AUTH: A/TREDICI, T. J. CORP: School of Aerospace Medicine, Brooks AFB, Tex. CSS: (Ophthalmology Branch.) In AGARD Spatial Disorientation in Flight 5 p (SEE N81-17698 08-52)

ABS: Spatial disorientation, visual restrictions, and illusions were examined as the possible causal factors in aircraft accidents. A number of aircraft accidents were analyzed in which visual illusions appear to be a significant or contributing factor in the accident. It is shown that such factors as rain on the windshield, flashblindness by high intensity strobe lights, disorientation by flickering lights, and ground light intensity variations appear to have led to errors in judgement, thus directly contributing to the aircraft accident. It is concluded that a studied awareness of these factors is the pilot's best corrective action available. 80/10/00 81N17703

UTTL: Human factors problems in general aviation

AUTH: A/SHELNUTT, J. B.; B/CHILDS, J. M.; C/PROPHET, W. W.; D/SPEARS, W. D. CORP: Seville Research Corp., Pensacola, Fla.

ABS: Approximately 80% of general aviation accidents in the past decade have been attributed to errors made by pilots. For this reason, the most promising approach to making substantial improvements in general aviation safety is through the systematic study of factors affecting the performance of general aviation pilots (i.e., human factors) and use of the resultant information to enhance pilot performance. In recognition of the need for comprehensive information to aid in the planning of such studies, the major objective of the work reported here was to identify and analyze human factors design issues related to the major performance problems of general aviation pilots. Thirty five such issues were identified, primarily through the review of the human factors, aircraft accident, and general aviation literature. The analysis and discussion of these issues was structured through the use of a conceptual model of the components of the general aviation system. Six such components were identified--(1) aircraft, (2) airports, (3) aeronautical information systems, (4) the pilot certification and ratings, and (5) continuation training and recurrent proficiency assessments.

RPT#: AD-A091670 SEVILLE-TR-78-01 FAA-CT-80-194 80/04/00 81N14625

UTTL: Development of a preprototype sabatier CO2 reduction subsystem

AUTH: A/KLEINER, G. N.; B/BIRBARA, P. CORP: Hamilton Standard, Windsor Locks, Conn.

ABS: A preoprototype Sabatier CO2 Reduction Subsystem was successfully designed, fabricated and tested. The lightweight, quick starting reactor utilizes a highly active and physically durable methanation catalyst composed of ruthenium on alumina. The use of this improved catalyst permits a single straight through plug flow design with an average lean component H2/CO2 conversion efficiency of over 99% over a range of H2/CO2 molar ratios of 1.8 to 5 while operating with flows equivalent to a crew size of one person steadystate to 3 persons cyclical (equivalent to 5 persons steady state). The reactor requires no heater operation after start-up even during simulated 55 minute lightside/39 minute darkside orbital operation over the above range of molar ratios and crew loadings. The subsystem's operation and performance is controlled by a microprocessor and displayed on a nineteen inch multi-colored cathode ray tube.

RPT#: NASA-CR-160885 SVHSER-7221 80/08/00 81N14624

UTTL: Status of improved autorotative landing capability research

AUTH: A/PLEASANTS, W. A., III; B/WHITE, G. T., III CORP: Army Research and Technology Labs., Fort Eustis, Va. CSS: (Applied Technology Lab.)

ABS: While the frequency of all emergency autorotative landings (i.e., rate per 100,000 flight hours) has decreased over the past several years for Army single-engine fleet helicopters, the percentage of unsuccessful landings resulting from emergency autorotations has remained relatively high. United States Army Safety Center accident statistics reveal that at least 30 percent of all emergency autorotative landings involving AH-1, UH-1, OH-58, and OH-6A helicopters result in some degree of vehicle damage or personnel injury. These statistics further indicate that the probability of each of these helicopters experiencing at least one emergency autorotation accident during an assumed 10,000-hour service life is as follows: OH-6(94.0%), AH-1(77.5%), OH-58(76.3%), and UH-1(63.3%). Recent design studies and supplementary research of previously documented findings indicate that it is possible to significantly improve helicopter autorotation capability and reduce demands on pilot skill through helicopter rotor energy augmenting concepts. This paper discusses results of

current studies as well as an outline for future in-depth research.
RPT#: AD-A090431 80/06/00 81N12072

UTTL: Aircraft accident report: Allegheny Airlines. Inc., Nord 262, Mohawk/Frakes 298, n29824, Benedum Airport, Clarksburg, West Virginia, February 12, 1979
CORP: National Transportation Safety Board, Washington, D. C.
ABS: At 1300 e.s.t., on February 12, 1979, a Nord 262, Mohawk/Frakes 298, N29824, operating as Allegheny Flight 561, departed Benedum Airport, Clarksburg, West Virginia, for National Airport, Washington, D.C., with 25 persons on board. The aircraft crashed about 14 sec after liftoff. Two persons were killed and eight persons were seriously injured; the aircraft was destroyed. The official weather at the time of departure was: Sky - partial obscuration, 1,000 ft overcast; visibility - 5/8 mi in snow; wind - calm; altimeter - 29.89 inHg. The National Transportation Safety Board determined that the probable cause of the accident was the captain's decision to take off with snow on the aircraft's wing and empennage surfaces which resulted in a loss of lateral control and a loss of lift as the aircraft ascended out of ground effect.
RPT#: NTSB-AAR-79-12 79/08/16 81N12044

UTTL: Postmortem coronary atherosclerosis finding in general aviation accident pilot fatalities: 1975 - 1977
AUTH: A/BOOZE, C. F., JR.; B/PIDKOWICZ, J. K.; C/DAVIS, A. W.; D/BOLDING, F. A. CORP: Federal Aviation Administration, Washington, D.C. CSS: (Office of Aviation Medicine.)
BS: The autopsies of 764 pilots involved in fatal general aviation accidents during the years 1975-1977 were reviewed to appraise the age specific prevalence of coronary atherosclerosis among the autopsied group. Fifty-one percent of the pilots killed in aircraft accidents and autopsied during 1975-77 were found to have some degree of coronary atherosclerosis ranging from minimal to severe. However, only about 5 percent of the autopsied group were categorized as having severe coronary atherosclerosis. The rate per 1,000 of severe coronary atherosclerosis increased with age from 14.5 for ages less than 30 to 89.9 for ages 50 years and above, with the rate nearly tripling from ages 30-39 to 40-49 (22.1 to 63.6). While the findings of this study are consistent with, and do parallel, the findings of other recent autopsy studies, the prevalence of coronary atherosclerosis among this group of autopsied airmen is less than would have been expected based on the results of these other studies.
RPT#: AD-A089428 FAA-AM-80-8 80/02/00 81N10693

UTTL: A tentative taxonomy of human interactive factors in aircraft mishaps
AUTH: A/WEGNER, K. W. CORP: Boston Coll., Chestnut Hill, Mass.
ABS: Previous research and results of the present study lend support to the concept of developing a taxonomy of factors or causes in aircraft mishaps. Twenty-five years of mishap research related to psychophysiological and environmental factors was reviewd to determine the most frequently occurring variables. Twenty-one of these were identified and classified into a tentative taxonomy under three functions: Equipment - Physical Environment, Management System, and Operator. Sixteen definitions related to these factors were available to analyze for reliability and relationship to the taxonomy functions. A survey form was developed which included the above definitions and nine selected aircraft mishap summaries. This instrument was administered to a Flight Safety Officer School class and a group of naive subjects of equivalent age and years of education. The task to be performed was to rate the presence or absence of these causes in each of the mishap summaries. Data analysis performed included the computation of mean agreement rates, inter-case consistency, intercorrelations of selected variables, and comparison of mean agreement rates and judged clarity of the definitions.
RPT#: AD-A088442 AFOSR-80-0595TR 80/05/00 80N33099

UTTL: Aircraft crashworthiness studies: Findings in accidents involving an aerial application aircraft
AUTH: A/KIRKHAM, W. R.; B/SIMPSON, J. M.; C/WALLACE, T. F.; D/GRAPE, P. M. CORP: Federal Aviation Agency, Oklahoma City, Okla. CSS: (Civil Aeromedical Inst.)
ABS: Aircraft crashworthiness features are presented. Modern aerial application aircraft are recognized as being the most crashworthy in the civil aviation fleet. Eighteen accidents involving an aerial application aircraft are presented. Crashworthiness is the protection by the aircraft against injury to the pilots from impact forces. The cockpit afforded good protection but in many of the accidents pilot restraint systems failed. There were no failures in lap belts or lap belt attachments. The structural attachment of the shoulder harness failed in a rare accident and the manufacturer strengthened the attachment. In three aircraft the inertia reel, to which the shoudler harness was attached, failed.

diminishing the effectiveness of the shoudler harness in attenuating impact forces on the pilots. In 14 of the 18 accidents the seat completely or partially separated from the seat track, and in 14 accidents one or more of the cast alloy seat legs or pedestals broke.

RPT#: AD-A084619 FAA-AM-80-3 80/04/00 80N32356

UTTL: Medical and toxicological factors in aircraft accidents

AUTH: A/KIRKHAM, W. R. CORP: Federal Aviation Administration, Washington, D.C. CSS: (Office of Aviation Medicine.) Presented at the 14th Ann. Southern Methodist Univ. Air Law Symp., Dallas, 6-8 Mar. 1980

ABS: A number of factors operating within pilots may impair their ability to operate aircraft in a safe manner, thus accounting for some of the 83 to 87 percent of pilot 'causes' of general aviation accidents. Aircraft accident investigators should be attuned to characteristics of the accident, witness statements, and autopsy and laboratory findings that may suggest partial or complete incapacitation in the pilot. Incapacitation may be brought on by a medical condition which may be revealed at autopsy or be inferred only from medical history. Spatial disorientation is a subjective evaluation only and a form of incapacitation rated as the third most frequent 'cause' of fatal general aviation accidents. Lack of oxygen--hypoxia--is a constant threat to incapacitate in aircraft operating at high altitudes. Toxicological factors such as alcohol, drugs, and gases (e.g., carbon monoxide) should always be sought in fatal aircraft accidents by obtaining blood, urine and other specimens for laboratory analyses. Aerial application pilots may be incapacitated by the poisonous materials they apply, especially the cholinesterase-inhibiting insecticides. The finding of therapeutic drugs in the blood or other specimens from accident victims, or of tablets, pills, etc., at the scene, may point to underlying medical conditions that may impair pilot performance. The author discusses these principles and illustrates them briefly with cases to make accident investigators and others aware of the importance of medical and toxicological factors in aircraft accidents.

RPT#: AD-A087690 FAA-AM-80-6 80/04/00 80N31373

UTTL: Light twin-engine aircraft accidents following engine failures CORP: National Transportation Safety Board, Washington, D. C. CSS: (Bureau of Technology.)

ABS: Data collected during the investigation of 477 light-twin aircraft accidents from 1972 through 1976 which involved engine failure or malfunction were studied. Pilot handbooks and other sources which provide information on engine-out performance and emergency procedures in light-twins were reviewed. A limited number of interviews with pilots and instructors were conducted. FAA training regulations were also studied. A major conclusion reached is that many of these accidents involved a lack of pilot proficiency in managing a light-twin after loss of power in one engine. Four recommendations are made to the FAA for corrective action and one previously made recommendation is reiterated.

RPT#: PB80-177306 NTSB-AAS-79-2 79/12/13 80N30287

UTTL: The current role of alcohol as a factor in civil aircraft accidents

AUTH: A/RYAN, L. C.; B/MOHLER, S. R. PAA: B/(Wright State Univ.) CORP: Federal Aviation Administration, Washington, D.C. CSS: (Office of Aviation Medicine.)

ABS: Ethyl alcohol continues as a serious adverse factor in general aviation flight safety. According to FAA figures, the level of alcohol-associated general aviation fatal accidents has remained relatively static at a 16% general level since 1969. A recent survey of the attitudes of pilots toward alcohol and flying reveals a lack of appreciation among one-third of the pilots concerning the adverse effects of alcohol and safe flight. A renewed pilot education program on alcohol and flight safety appears indicated.

RPT#: AD-A086261 FAA-AM-80-4 80/05/00 80N29266

UTTL: The 1976 accident experience of civilian pilots with static physical defects

AUTH: A/DILLE, J. R.; B/BOOZE, C. F. CORP: Federal Aviation Administration, Washington, D.C. CSS: (Office of Aviation Medicine.)

ABS: The 1974 and 1975 aircraft accident experiences of civilian pilots with eight selected static physical defects have been examined and reported previously. Three categories, blindness or absence of either eye, deficient color vision with a waiver, and deficient distant vision, had significantly more accidents than were expected on the basis of observed-to-expected ratios. However, pilots with these conditions reported considerably higher median 6-month flight times than

did an active airman population sample and accident airmen without selected pathology. In 1975 the reported recent and total flying times for all airmen with these defects were determined and accident rates were calculated. The rates for airmen with blindness or absence of an eye were still found to be significantly higher. The contact lens group was also selected to receive special attention in a study of the 1976 accident data because marginal significance was found on analysis of the 1975 data and. after 1976. this group will not carry a pathology code or require a waiver and thus will be difficult to study. Observed-to-expected ratios for 1976 are 1.91 for deficient color vision with a waiver. 1.28 for contact lens users. 1.37 for blindness or absence of either eye. and 1.62 for deficient distant vision. The accident rates per 100.000 hours of cumulative and last 6 months' flying experience were significantly greater for contact lens users and monocular pilots than for the active airman population.

RPT#: AD-A077189 FAA-AM-79-19 79/08/00 80N27304

UTTL: Flight-deck automation: Promises and problems

AUTH: A/WIENER. E. L.: B/CURRY. R. E. PAA: A/(Miami Univ.. Coral Gables. Fla.) CORP: National Aeronautics and Space Administration. Ames Research Center. Moffett Field. Calif.

ABS: The state of the art in human factors in flight-deck automation is presented. A number of critical problem areas are identified and broad design guidelines are offered. Automation-related aircraft accidents and incidents are discussed as examples of human factors problems in automated flight.

RPT#: NASA-TM-81206 A-8210 80/06/00 80N26040

UTTL: Lateral rollover protection concepts

AUTH: A/FOX. R. G. CORP: Textron Bell Helicopter. Fort Worth. Tex.

ABS: Helicopter accidents in which the aircraft rolled over laterally are costly in aircraft damage. U.S. Army helicopter accident reports involving lateral rollover for a 6 1/2 year period were analyzed to determine their significant characteristics such that design concepts for rollover protection could be identified. The results of the accident analysis were applied to portions of crash survival specifications and design concepts for rollover protection. Dynamic rollover. when the aircraft is light on its landing gear. was investigated using computer simulation to identify pertinent parameters. A quick response from the pilot to reduce main rotor thrust is the primary means available for recovery. A preliminary evaluation of the KRASH computer simulation program was done for the rollover environment. Design concepts that either prevented the occurrence of a rollover accident or minimized the dangers to the occupants as the aircraft rolled over were investigated. An automatic rollover sensing and correction system was investigated. Wing and wide landing gear concepts can provide increased rollover resistance. Means of preventing hazardous main rotor pylon motion during a rollover accident were also investigated.

RPT#: AD-A081420 USAAVRADCOM-TR-80-D-1 80/01/00 80N24284

UTTL: Aviation accidents and the theory of the situation

AUTH: A/BOLMAN. L. CORP: Harvard Univ.. Cambridge. Mass. CSS: (Graduate School of Education.) In NASA. Ames Res. Center Resource Management on the Flight Deck p 31-58 (SEE N80-22283 13-03)

ABS: Social-psychological factors effecting the performance of flight crews are examined. In particular. a crew member's perceptual-psychological constructs of the flight situation (theories of the situation) are discussed. The skills and willingness of a flight crew to be alert to possible errors in the theory become critical to their effectiveness and their ability to ensure a safe flight. Several major factors that determine the likelihood that a faulty theory will be detected and revised are identified. 80/03/00 80N22285

UTTL: Aircraft emergency decisions: Cognitive and situational variables

AUTH: A/HOPF-WEICHEL. R.: B/LUCACCINI. L.: C/SALEM. J.: D/FREEDY. A. CORP: Perceptronics. Inc.. Woodland Hills. Calif.

ABS: Military aircraft accidents are important not only to the individuals directly involved. but also to those responsible for preparing and maintaining combat-ready forces for the nation's defense. This report addresses problems underlying aircraft emergency situations. A literature review provided background information. and an analysis of selected accident reports. A workshop was convened to review the state-of-the-art of aircrew emergency decision training. safety research. and behavioral decision theory. A selected set of emergency situations was the basis of a preliminary classification of aircraft emergency situations in terms of several situational and decision making attributes. The classification is based on data derived from interviews with experienced military flying personnel. A taxonomy of emergency situation

types was developed, incorporating both situational and task specific elements as cognitive attributes of the decision tasks performed under emergency conditions. On the basis of the taxonomy, three classes of emergency situations were found to be of interest: Situation 1 (predictable) Situation 2 (partly predictable), and Situation 3 (unpredictable). Initial training guidelines are suggested in light of the cognitive requirements of each class.

RPT#: AD-A077413 PATR-1065-79-7 AFOSR-79-1175TR 79/07/00 80N19051

UTTL: Human factors in high speed low level accidents: A 15 year review

AUTH: A/RUD, R. C.; B/LEBEN, D. F. CORP: Defence and Civil Inst. of Environmental Medicine, Downsview (Ontario).

ABS: The Canadian Forces introduced the gf 104G into Squadron Operation in 1963 and since that time these aircraft have operated in the high-speed, low-level environment in both the strike/reconnaissance and tactical support roles. Fifty-seven accidents involving these aircraft are reviewed with regard to cause factors. Marginal weather appears to be the one most significant factor contribution to low-level, high-speed accidents however, several human factors such as visual contrast problems, fatigue, stress, reaction time, 'mission completion' syndrome, inattention and task overload were identified. Aspects of accidents which typify human factors problems are described. Suggested possible preventive measures are outlined.

RPT#: AD-A076221 DCIEM-79-R-35 79/07/00 80N18012

UTTL: Some human factors issues in the development and evaluation of cockpit alerting and warning systems

AUTH: A/RANDLE, R. J., JR.; B/LARSEN, W. E.; C/WILLIAMS, D. H. CORP: National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

ABS: A set of general guidelines for evaluating a newly developed cockpit alerting and warning system in terms of human factors issues are provided. Although the discussion centers around a general methodology, it is made specifically to the issues involved in alerting systems. An overall statement of the current operational problem is presented. Human factors problems with reference to existing alerting and warning systems are described. The methodology for proceeding through system development to system test is discussed. The differences between traditional human factors laboratory evaluations and those required for evaluation of complex man-machine systems under development are emphasized. Performance evaluation in the alerting and warning subsystem using a hypothetical sample system is explained.

RPT#: NASA-RP-1055 A-7696 80/01/00 80N15821

UTTL: An assessment of and approach to the validation of digital flight control systems

AUTH: A/MULCARE, D. B.; B/NESS, W. G. CORP: Lockheed-Georgia Co., Marietta. In AGARD Advan. in Guidance and Control Systems Using Digital Tech. 12 p (SEE N80-14017 05-01)

ABS: Flight-critical digital flight control system functions are evaluated in the context of farther term implementations. The quality and safety associated with fault tolerant, highly integrated, control oriented system implementations are emphasized. Technology needs are addressed so that the verification and validation process for advanced digital flight control systems can be sufficiently developed and purposefully accomodated in system engineering methodologies. 79/08/00 80N14036

UTTL: A method for assessing the impact of wake vortices of USAF operations

AUTH: A/KURYLOWICH, G. CORP: Air Force Flight Dynamics Lab., Wright-Patterson AFB, Ohio.

ABS: Experience as a consultant to the Safety Office at Norton AFB led to compiling the engineering tools presented, so that this report can be used by engineering personnel to investigate future incidents/accidents and existing USAF operations that are impacted by the vortical wake hazard. The approach presented is amenable to easy hand computations. Mixed airplane/helicopter operations can be assessed, since the engineering tools to determine the location and strength of the rotor downwash field behind a helicopter are presented. Finally, a simplified mathematical model is given to represent this hazard for use in USAF simulators, to make pilots aware of the problems associated with operating in wake-contaminated airspace.

RPT#: AD-A072967 AFFDL-TR-79-3060 79/07/00 80N12072

UTTL: Light airplane crash tests at three pitch angles

AUTH: A/VAUGHAN, V. L., JR.; B/ALFARO-BOU, E. CORP: National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

ABS: Three similar twin-engine general aviation airplane specimens were crash tested at an impact dynamics research facility at 27 m/sec, a flight path angle of

-15 deg. and pitch angles of -15 deg. 0 deg. and 15 deg. Other crash parameters were held constant. The test facility, instrumentation, test specimens, and test method are briefly described. Structural damage and accelerometer data for each of the three impact conditions are presented and discussed.
RPT#: NASA-TP-1481 79/11/00 80N11505

UTTL: Aircraft accident report - United Airlines, Inc., McDonnell-Douglas DC-8-61, N8082U, Portland, Oregon, December 28, 1978 CORP: National Transportation Safety Board, Washington, D. C.
ABS: The crash of flight 173, a DC 8 aircraft, is investigated. The cause of the accident is listed as flight crew error in responding to the low fuel state of the aircraft due to a malfunction in the landing gear. Damage to the aircraft and injuries to persons are reported. Wreckage information, an aircraft systems examination, a fuel control test, and a report of the main landing gear retract cylinder assembly are discussed.
RPT#: NTSB-AAR-79-7 79/06/07 80N11051

UTTL: Human factors in production and prevention of aircraft accidents due to disorientation in flight
AUTH: A/ROTONDO, G. CORP: Italian Air Force Medical Service H. Q., Rome. In AGARD Human Factors Aspects of Aircraft Accidents and Incidents 6 p (SEE N79-31942 22-54)
ABS: To prevent and reduce those flight accidents occasionally due to spatial disorientation, which are tied to the human factor and whose causes can, therefore, be influenced and corrected, it is very important that the pilot has exact knowledge of the possible illusory phenomena which can occur in flight, the awareness that they can be anticipated, and finally that timely actuation of adequate preventive measures allows one to avoid loss of orientation during the various conditions of flight. For that reason the most frequent circumstances and conditions should be examined which can facilitate spatial disorientation in the pilot favoring the mental conflict which originates when there is sensorial incongruity between erroneous sensations coming from the vestibular apparatus and/or the proprioceptors and inadequate visual information. The possible measures necessary to prevent those various conditions contributing to or facilitating disorientation in flight, or neutralizing them whenever they are already in effect, are discussed. 79/06/00 79N31952

UTTL: Geographical disorientation and flight safety
AUTH. A/TAYLOR, R. M. CORP: Institute of Aviation Medicine, Farnborough (England). CSS: (General Psychology Section.) In AGARD Human Factors Aspects of Aircraft Accidents and Incidents 11 p (SEE N79-31942 22-54)
ABS: Geographical orientation is the psychological process whereby the aircraft pilot maintains an awareness of his position in relation to geographical points. The antithesis, geographical disorientation is a common occurrence in flight, the consequences of which vary in seriousness. Case studies of individual accidents and incidents indicated that in many respects geographical disorientation in flight can be as insidious, compelling and as stressful as spatial disorientation. Geographical disorientation may precipitate spatial disorientation and vice versa. In severe cases, where the realization of the error is sudden, there is evidence of panic and disorganization of behavior leading to loss of control of the aircraft. Preventative actions that may reduce the incidence of geographical disorientation include better training and preflight planning, improved awareness of the problem, elimination of system induced errors, and improved navigation aids, including maps and charts. 79/06/00 79N31951

UTTL: Pilot incapacity in flight
AUTH: A/READER, D. C. CORP: Institute of Aviation Medicine, Farnborough (England). In AGARD Human Factors Aspects of Aircraft Accidents and Incidents 5 p (SEE N79-31942 22-54)
ABS: Incapacity of any crew member of an airplane can have serious implications for the aircraft and occupants. However, in the case of the pilot, the outcome can be disastrous. The hazards of pilot incapacity can be reduced by carrying more than one pilot (such as in transport aircraft). The pilot can be removed from the controls in time to retain control of the aircraft. However, under certain conditions (for instance at low altitudes) this may not be possible; moreover, the pilot may slump forward and restrict the controls. Various restraint systems were devised and these were considered in turn to determine whether their use could avoid the hazards. The incidence of pilot incapacitation was reviewed in both military and civil aircraft and the risk compared with other flight hazards. 79/06/00 79N31950

UTTL: Analyses of midair collisions in German airspace: Methodology and results

AUTH: A/WEBER, O. CORP: Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Brunswick (West Germany). In AGARD Human Factors Aspects of Aircraft Accidents and Incidents 14 p (SEE N79-31942 22-54)

ABS: Theoretical studies concerning conflict detection and resolution in visual meteorological conditions by means of the see and avoid concept, and lessons learned from analyses of midair accidents in German airspace are addressed. The methodology is concerned with some supplementary aspects of the visual detection of an aircraft, the observation and extrapolation of its flight path, and the distance limits where an efficient maneuver can be initiated taking observation errors into account. Restrictions of a pilot's ability to detect an approaching aircraft caused by a small apparent size or unfavorable silhouette of that aircraft, and by opaque structures in his cockpit are discussed. Also treated is the apparent track of an aircraft on the windshield in front of the observing pilot. The features of five real midair conflicts in German airspace are demonstrated. 79/06/00 79N31949

UTTL: Analysis of the intervention of the human factor as a principal cause or influence in accidents of Mirage aircraft in the Belgian Air Force

AUTH: A/FLION, A. CORP: Belgian Air Force, Brussels. In AGARD Human Factors Aspects of Aircraft Accidents and Incidents 6 p (SEE N79-31942 22-54)

ABS: Statistics are presented showing that, between 1971 and 1977, human factors were responsible for 56 of 91 accidents involving Mirage aircraft used by the Belgian Air Force. Certain parameters likely to be considered eventually in the notion of human factors are analyzed. These include the age of the pilot, his flight experience, the circumstances of the accident in the design of the mission accomplished, the pilot's previous medical history (both physical and psychical), the intervention of leadership, and the interferential factors happening unexpectantly in the triangle formed by man-medium-machine. The effects of the accidents on the pilots are analyzed showing the injuries received, the duration of limited aptitude, and their post-accident careers. 79/06/00 79N31945

UTTL: Medical and operational factors of accidents in advanced fighter aircraft

AUTH: A/JOHNSON, L. W., JR. CORP: Tactical Air Command, Langley AFB, Va. CSS: (Aerospace Medicine Div.) In AGARD Human Factors Aspects of Aircraft Accidents and Incidents 4 p (SEE N79-31942 22-54)

ABS: The proper mix and interface between improving aircraft capabilities and man's capabilities and limitations produce success in aerial and aerospace operations. A dysequilibrium between the medical and operational aspects of man and aircraft combine to produce accidents. Some of man's physiological systems and advanced fighter aircraft characteristics are described as well as multiple operational requirements imposed on men who fly high performance fighter aircraft. The interface between the operational requirements and the medical aspects of some of the accidents therein are related. The establishment, in NATO, of a viable aircraft accident information gathering and dissemination program which would prevent accidents in advanced fighter aircraft is proposed. 79/06/00 79N31944

UTTL: Three decades of USAF efforts to reduce human error accidents, 1947-1977

AUTH: A/ZELLER, A. F. CORP: Air Force Inspection and Safety Center, Norton AFB, Calif. CSS: (Life Sciences Div.) In AGARD Human Factors Aspects of Aircraft Accidents and Incidents 9 p (SEE N79-31942 22-54)

ABS: Thirty years after the formal inception of the USAF, major accidents had been reduced from 1,555 to 90. Human error associated with these accidents was reduced as much as material and other involvements. Analysis of the preventive efforts shows three distinct, although overlapping, approaches which have been employed. The administrative approach is the best known. This investigate-evaluate-fix cycle is the common dimension of almost all accident prevention effort. The scientific approach supplements the information by centering upon a systematic and intensive evaluation of human limitations in a defined man/machine setting. The third concept, total system management, emphasizes improvement in the management of the entire system, though the details of what will be instrumental in the prevention of a specific accident are often not defined. In practice, a viable accident prevention program incorporates all three approaches, with emphasis defined in relation to need. 79/06/00 79N31943

UTTL: Human Factors Aspects of Aircraft Accidents and Incidents
AUTH: A/HARTMAN, B. O. PAA: A/(School of Aerospace Medicine) CORP: Advisory Group for Aerospace Research and Development, Neuilly-Sur-Seine (France). Presented at the Aerospace Med. Panel Specialists' Meeting, Paris, 6-10 Nov. 1978
RPT#: AGARD-CP-254 ISBN-92-835-0241-8 AD-A073812 79/06/00 79N31942

UTTL: Injury mechanisms analysis in aircraft accidents
AUTH: A/HILL, I. R. CORP: Royal Air Force, Halton (England). CSS: (Inst. of Pathology and Tropical Medicine.) In AGARD Models and Analogues for the Evaluation of Human Biodyn. Response, Performance and Protect. 10 p (SEE N79-31901 22-52)
ABS: An analysis of 30 fatal aircraft accidents, some of which were survivable shows that the basic mechanisms of injury are common to many different accidents. From the investigation the following conclusions can be made: (1) serious or fatal head injury is the single most serious problem in aircraft accidents, particularly in light aircraft; (2) there is a wide margin in injury severity between survivors and fatalities; (3) restraint systems are still inadequate, especially for passengers; (4) the severity of injury is increased by: (a) 'ejection' from the aircraft, (b) severe damage to the airframe, (c) poor design features such as badly sited fuel tanks; (5) the principle method of serious injury is forward flexion over a lap belt; and (6) mathematical scoring of injuries makes more accurate analysis of accidents a feasible proposition. 79/06/00 79N31913

UTTL: Aircraft accident report: United Airlines, Inc., Douglas DC-8-54, N8047U near Kaysville, Utah, 18 December 1977 CORP: National Transportation Safety Board, Washington, D. C.
ABS: About 0138 m.s.t. on December 18, 1977, a United Airlines, Inc., DC-8F-54 cargo aircraft, operating as Flight 2860, crashed into a mountain in the Wasatch Range near Kaysville, Utah. The three flightcrew members, the only persons aboard the aircraft, were killed, and the aircraft was destroyed. Flight 2860 encountered electrical system problems during its descent and approach to the Salt Lake City Airport. The flight requested a holding clearance which was given by the approach controller and accepted by the flightcrew. The flight then requested and received clearance to leave the approach control frequency for a little minute to communicate with company maintenance. Flight 2860 was absent from the approach control frequency for about 7 1/2 minutes. During that time, the flight entered an area near hazardous terrain. The approach controller recognized Flight 2860's predicament but was unable to contact the flight. When Flight 2860 returned to approach control frequency, the controller told the flight that it was too close to terrain on its right and to make a left turn. After the controller repeated the instructions, the flight began a left turn and about 15 seconds later the controller told the flight to climb immediately to 8,000 feet. Eleven seconds later, the flight reported that it was climbing from 6,000 feet to 8,000 feet. The flight crashed into a 7,665-foot mountain near the 7,200-foot level. The National Transportation Safety Board determines that the probable cause of this accident was the approach controller's issuance and the flightcrew's acceptance of an incomplete and ambiguous holding clearance in combination with the flightcrew's failure to adhere to prescribed impairment-of-communications procedures and prescribed holding procedures. The controller's and flightcrew's actions are attributed to probable habits of imprecise communication and of imprecise adherence to precedures developed through years of exposure to operations in a radar environment. Contributing to the accident was the failure of the aircraft's No. 1 electrical system for unknown reasons.
RPT#: NTSB-AAR-78-8 78/07/27 79N29159

UTTL: Aircraft accident report: Continental Air Lines, Inc., Boeing 727-224, N32725, Tucson Arizona, 3 June 1977 CORP: National Transportation Safety Board, Washington, D. C.
ABS: The aircraft was damaged substantially after striking the powerlines and utility poles, which were located about 130 feet to the left of the runway centerline and about 710 feet from the departure end of the runway. The aircraft was landed safely at the Tucson Airport; there were no injuries. The National Transportation Safety Board determines that the probable cause of the accident was the captain's decision to take off under evident hazardous wind conditions which resulted in an encounter with severe wind shear and subsequent collision with obstacles in the takeoff path. The rate of climb of the aircraft in these conditions when flown according to prescribed operating procedures was not sufficient to clear the obstacles. If the aircraft's full aerodynamic capability was used, collision with obstacles probably could have been avoided.
RPT#: NTSB-AAR-78-9 78/08/01 79N29158

UTTL: Aircraft accident report: Rocky Mountain Airways, Inc., DeHavilland DHC-6-300, N24RM, Cheyenne, Wyoming, 27 February 1979 CORP: National Transportation Safety Board, Washington, D. C.

ABS: About 0807 mountain standard time, Rocky Mountain Airways, Inc., Flight 801, crashed into rolling terrain shortly after takeoff in visual flight conditions from runway 34 at Cheyenne Municipal Airport, Wyoming. The aircraft came to rest about 1.3 nmi east of the departure end of the runway. There were 14 passengers and a crew of 2 aboard; 2 passengers were injured slightly. The aircraft was damaged substantially. The National Transportation Safety Board determined that the probable cause of the accident was the flightcrew's erroneous determination that the aircraft was not capable of single-engine flight and their actions which precluded obtaining maximum available performance from the aircraft. The cause of the engine failure was an erroneous assessment by company maintenance personnel of damage sustained by the right engine during an overtemperature condition and their poor judgment in deciding to repair and release the engine for flight without replacing the engine's power turbine section.

RPT#: NTSB-AAR-79-10 79/07/19 79N29157

UTTL: US Army aviation fatigue-related accidents, 1971-1977

AUTH: A/KRUGER, G. P.; B/JONES, Y. F. CORP: Army Aeromedical Research Lab., Fort Rucker, Ala.

ABS: An accident data survey was made to determine how frequently aviator crew fatigue may have contributed to US Army aviation accidents from 1971 to 1977. All accident reports in the US Army Agency for Aviation Safety (USAAAVS) data base were reviewed Aviator fatigue was deemed to be a contributing factor in 42 rotary wing accidents which resulted in a total of 51 fatalities and 63 personnel injuries. Fatigue contributed to 10 fixed wing accidents, resulting in 3 fatalities and 5 injuries. This paper categorizes these fatigue related accidents by aircraft and mission type and by time of day and day of week of the accident. It also tabulates pilot activities prior to the accidents which promote the likelihood of pilot fatigue contributions. The personnel and equipment costs of these accidents to the Army are estimated, and the relative importance of such accidents to the total US Army aviation accident picture is assessed.

RPT#: AD-A062486 USAARL-79-1 78/10/00 79N20725

UTTL: Engineering analysis of crash injury in army aircraft

AUTH: A/HICKS, J. E. CORP: Army Agency for Aviation Safety, Fort Rucker, Ala. In AGARD Operational Helicopter Aviation Med. 11 p (SEE N79-19605 10-51)

ABS: A methodology for identification of crashworthiness deficiencies in Army aircraft is discussed. The methodology provides for injury and impact data to be extracted from accident reports using a specially developed injury coding system. Personnel injuries are costed through a technique which provides for consideration of each injury based on its relative severity as determined by medical examination. Crash injury causes are identified and ranked according to the magnitude of their effect and probability of occurrence. The technique is designed to provide recommendations as to the most urgent crashworthiness research/development/procurement efforts for consideration by aircraft systems managers and aviation research laboratories. An application of the methodology to an operated Army aircraft is shown. Preliminary results as to the more significant crash hazards in this aircraft are discussed. Recommendations are made as to the use of the methodology and to additional investigation aids which would improve the future identificat ons of crash hazards. 78/12/00 79N19655

UTTL: Comparative injury patterns in US Army helicopters

AUTH: A/SAND, L. D. CORP: Army Agency for Aviation Safety, Fort Rucker, Ala. In AGARD Operational Helicopter Aviation Med. 7 p (SEE N79-19605 10-51)

ABS: The type of injuries, body area injured, and cause of injuries to 740 U.S. Army aviators involved in 388 rotary wing accidents from 1 January 1972 through 30 September 1977 are examined. Considerations are given to two main areas: (1) relationship to injury regarding the aviator's height, weight, and location aboard the aircraft, cockpit condition, and aircraft altitude; and (2) comparison of present injury experience with previous injury studies. The results, through statistical analyses, show that not one, or even combinations, of those factors listed were significant in injury causation. Further, comparisons of injuries show that the overall injury pattern has not changed significantly in the past 20 years. For example, injuries to the extremities, the head, and the spine continue to be among the leading body areas to be injured. Also, 94 percent of all accidents from 1957 to the present were classified as survivable but produced 33 percent of all fatalities. 78/12/00 79N19654

UTTL: Occupant injury mechanisms in civil helicopter accidents

**AUTH:** A/SNYDER, R. G. CORP: Michigan Univ., Ann Arbor. CSS: (Inst. of Highway Safety Research.) In AGARD Operational Helicopter Aviation Med. 14 p (SEE N79-19605 10-51)

**ABS:** Mechanisms incurred in several selected accidents involving roll-over, rotor blade strike, and seat and restraint system failures are discussed. The present injury and fatality rate could be reduced in civil accidents by improved restraints, including use of upper-torso belts, energy-absorbing seats, crashworthy fuel systems, and increased use of protective helmets. 78/12/00 79N19653

UTTL: US Army aviation fatigue-related accidents, 1971 - 1977

**AUTH:** A/KRUEGER, G. P.; B/JONES, Y. F. CORP: Army Aeromedical Research Lab., Fort Rucker, Ala. In AGARD Operational Helicopter Aviation Med. 11 p (SEE N79-19605 10-51)

**ABS:** An accident data survey was made to determine how frequently aviator crew fatigue may have contributed to US Army aviation accidents from 1971 to 1977. All accident reports in the US Army Agency for Aviation Safety (USAAAVS) data base were reviewed. Aviator fatigue was deemed to be a contributing factor in 42 rotary wing accidents which resulted in a total of 51 fatalities and 63 personnel injuries. Fatigue contributed to 10 fixed wing accidents, resulting in three fatalities and five injuries. These fatigue related accidents are categorized by aircraft and mission type and by time of day and day of week of the accident. Pilots activities prior to the accidents which promote the likelihood of pilot fatigue contributions are described. The personnel and equipment costs of these accidents to the Army are estimated, and the relative importance of such accidents to the total US Army aviation accident picture is assessed. 78/12/00 79N19621

UTTL: Aircraft accident report: Allegheny Airlines, Inc. BAC 1-11, N1550, Rochester, New York, July 9, 1978 CORP: National Transportation Safety Board, Washington, D. C. CSS: (Bureau of Accident Investigation.)

**ABS:** After completing a precision approach and landing in visual flight conditions, the aircraft overran the end of the runway, crossed a drainage ditch and came to rest 728 ft past the end of the runway threshold. Although the aircraft was damaged substantially when it hit the drainage ditch, there was no fire. There were 73 passengers and a crew of 4 on board; one passenger was injured seriously. The probable cause of the accident was the captain's complete lack of awareness of airspeed, vertical speed, and aircraft performance throughout an ILS approach and landing in visual meteorological conditions which resulted in his landing the aircraft at an excessively high speed and with insufficient runway remaining for stopping the aircraft, but with sufficient aircraft performance capability to reject the landing well after touchdown. Contributing to the accident was the first officer's failure to provide required callouts which might have altered the captain to the airspeed and sink rate deviations. The Safety Board was unable to determine the reason for the captain's lack of awarness or the first officer's failure to provide required callouts.

**RPT#:** NTSB-AAR-73-2 79/02/08 79N18951

UTTL: Briefs of accidents involving alcohol as a cause/factor, US general aviation, 1977 CORP: National Transportation Safety Board, Washington, D. C. CSS: (Bureau of Technology.)

**ABS:** There are 47 accidents included, 41 of which involve fatal accidents. The facts, conditions, circumstances, and probable cause(s)/factor(s) for each accident are presented. Additional statistical information is tabulated by type of accident, phase of operation, injury index, aircraft damage, pilot certificate, injuries, and causal factor(s).

**RPT#:** NTSB-AMM-78-17 PB-293065 78/12/19 79N17833

UTTL: Briefs of fatal accidents involving weather as a cause/factor, US general aviation, 1977 CORP: National Transportation Safety Board, Washington, D. C. CSS: (Bureau of Technology.)

**ABS:** Reports are presented of all fatal U.S. general aviation accidents involving weather as a cause/factor for the year 1977. Included are 258 fatal accidents in the brief format. This format presents the facts, conditions, circumstances, and probable cause(s) for each accident. Additional statistical information is tabulated on all accidents involving weather as a cause/factor by type of accident, phase of operation, injury index, aircraft damage, pilots certificate, injuries and cause/factor(s).

**RPT#:** NTSB-AMM-78-16 PB-293261 78/12/19 79N17832

UTTL: Briefs of accidents involving rotorcraft. US general aviation. 1977 CORP: National Transportation Safety Board. Washington. D. C. CSS: (Bureau of Technology.)

ABS: There are 276 accidents included. 29 of which involve fatal accidents. The facts. conditions. circumstances. and probable cause(s) for each accident are presented. Additional statistical information is tabulated by type of accident. phase of operation. injury index. aircraft damage. kind of flying. pilot certificates. injuries. and causes and related factors.

RPT#: NTSB-AMM-78-15 PB-293362 78/12/19 79N17831

UTTL: Briefs of accidents involving midair collisions. US general aviation. 1977 CORP: National Transportation Safety Board. Washington. D. C. CSS: (Bureau of Technology.)

ABS: There are 34 accidents included. 17 of which involve fatal accidents. The facts. conditions. circumstances. and probable cause(s) for each accident are presented. Additional statistical information is tabulated by kind of flying. phase of operation. injury index. altitude of occurrence. airport proximity. aircraft damage. pilot certificate. injuries. and casual factor(s).

RPT#: NTSB-AMM-78-13 PB-293499 78/12/19 79N17829

UTTL: Agricultural aviation versus other general aviation: Toxicological findings in fatal accidents

AUTH: A/LACEFIELD. D. J.: B/ROBERTS. P. A.: C/BLOSSOM. C. W. CORP. Civil Aeromedical Inst.. Oklahoma City. Okla.

ABS: Results from the toxicological study of samples from 174 pilots killed while engaged in aerial application and samples from 2.449 other general aviation pilots are compared. The incidence of alcohol in specimens was similar for ag pilots and other general aviation pilots but the blood levels of alcohol tended to be lower in the ag pilots. Carbon monoxide as an incapacitating agent did not appear to be a factor in aerial application operations. Evidence of the use of drugs or medications was less in ag pilots than in other general aviation pilots. Over half of the ag pilots had below normal cholinesterase levels. suggesting a continuing problem of acute and/or chronic toxicity from the pesticides being applied by agricultural aircraft. This finding suggests that better educational efforts could reduce the accident rate in this important segment of our agricultural activity.

RPT#: AD-A060110 FAA-AM-78-31 78/09/00 79N15012

UTTL: Analysis of naval aviation head and neck injuries (1969-1978)

AUTH: A/TYNDALL. L. H.: B/CARR. R. W. CORP: Dynamic Science. Phoenix. Ariz.

ABS: U.S. Naval aviation accidents during the period January 1969 to March 1978 were reviewed to study the nature and severity of injuries to the head and neck. Results. by aircraft models and types. were tabulated and analyzed to determine the number and types of injuries to the skull. face. eyes. neck. and cervical vertebra: this information was then used to determine the primary impact force direction. The role of the helmet in injury causation or prevention was also considered in the final directional determination.

RPT#: AD-A057657 REPT-0249-78-81 78/05/00 79N11689

UTTL: Briefs of accidents involving alcohol as a cause/factor. US general aviation. 1976 CORP: National Transportation Safety Board. Washington. D. C. CSS: (Bureau of Technology.)

ABS. All U.S. general aviation accidents. occurring in 1976. involving alcohol impairment as a cause/factor are reported. Fifty-four accident briefs are included. forty-four of which involve fatal accidents. The brief format presents the facts. conditions. circumstances and probable cause(s)/factor(s) for each accident. Additional statistical information is tabulated by type of accident. phase of operation. injury index. aircraft damage. pilot certificate. injuries and causal factor(s).

RPT#: PB-283005/7 NTSB-AMM-78-6 78/04/13 79N11021

UTTL: Briefs of fatal accidents involving weather as a cause/factor. US general aviation. 1976 CORP: National Transportation Safety Board. Washington. D. C. CSS: (Bureau of Technology.)

ABS: All fatal U.S. general aviation accidents involving weather as a cause/factor for the year 1976 are reported. Two hundred and sixty-two fatal accidents in the brief format are included. This format presents the facts. conditions. circumstances. and probable cause(s) for each accident. Statistical information is tabulated on all accidents involving weather as a cause/factor by type of accident. phase of operation. injury index. aircraft damage. pilots certificate. injuries and cause/factor(s).

RPT#: PB-283004/0 NTSB-AMM-78-5 78/04/13 79N11020

UTTL: Single pilot IFR operating problems determined from accidental data analysis

AUTH: A/FORSYTH, D. L.; B/SHAUGHNESSY, J. D. PAA: A/(Florida Univ., Gainsville) CORP: National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

ABS: The accident reports examined were restricted to instrument rated pilots flying in IFR weather. A brief examination was made of accidents which occurred during all phases of flight and which were due to all causes. A detailed examination was made of those accidents which involved a single pilot which occurred during the landing phases of flight, and were due to pilot error. Problem areas found include: (1) landing phase operations especially final approach, (2) pilot weather briefings, (3) night approaches in low IFR weather, (4) below minimum approaches, (5) aircraft icing, (6) imprecise navigation, (7) descending below minimum IFR altitudes, (8) fuel mismanagement, (9) pilot overconfidence, and (10) high pilot workload especially in twins. Some suggested areas of research included: (1) low cost deicing systems, (2) standardized navigation displays, (3) low cost low-altitude warning systems (4) improved fuel management systems, (5) improved ATC communications, (6) more effective pilot training and experience acquisition methods, and (7) better weather data dissemination techniques.

RPT#: NASA-TM-78773 78/09/00 /3N11013

UTTL: Judgement evaluation and instruction in civil pilot training

AUTH: A/JENSEN, R. S.; B/BENEL, R. A. CORP: Illinois Univ., Savoy. CSS: (Aviation Research Lab.)

ABS: The nature of good flying judgment and its acquisition, development, and evaluation are examined from the perspectives of aviation and psychology. A definition of pilot judgment is presented consisting of an intellective part (How well can you think?) and a motivative part (are you cautious or risky?). Evidence from research in other fields indicates that both aspects of judgement can be taught and evaluated. A broad outline for a judgment training and evaluation program is presented along with techniques to be implemented in ground school and aircraft training.

RPT#: AD-A057440 FAA-RD-78-24 77/12/00 79N10737

UTTL: Preliminary design of an accident Information Retrieval System (AIRS)

AUTH: A/ASK, H. R.; B/MOFFATT, M. E.; C/HUGHES, I.; D/BROCK, L.; E/BIKOWSKI, J.; F/BRAHM, C. B. CORP: United Technologies Corp., Windsor Locks, Conn. CSS: (Hamilton Standard Div.)

ABS: This report covers the phase 1 activity entitled Concept Investigation and phase 2 entitled Preliminary Design and System Analysis. The report details the analyses involving requirements, parameters, trade-offs, and definition of a recommended AIRS. The Phase 1 effort included the intense analysis of the airborne portion of the system since it is the most sensitive element in terms of size, weight, and cost. This included examination of the parameter and sensor requirements, survivability and software. Actual flight data was used to run a program on a large-scale computer to determine limits, accuracy, and sampling rate effects on flight data reconstruction and aircraft memory storage requirements. Phase 2 included a detailed preliminary design of the AIRS. A preliminary hardware concept was established and the essential features of the recommended concept are included. The recommended system was analyzed to determine performance, weight, size, cost, installation, survivability, reliability, data retrieval, maintenance and functional test factors. Results indicate that the current state of the art will allow an AIRS to be developed for installation on production UTTAS and AAH aircraft. The recommended system employs an all solid-state design including the mass data storage device. Factors of two or more improvements in size, weight, reliability, maintainability are indicated over current data recording systems.

RPT#: AD-A055590 HSER-7342 USARTL-TR-77-51 78/04/00 78N31952

UTTL: Overview of safety research

AUTH: A/ENDERS, J. H. CORP: National Aeronautics and Space Administration, Washington, D. C. In NASA. Langley Res. Center CTOL Transport Technol., 1978 p 735-756 (SEE N78-29046 20-01)

ABS: Aircraft safety is reviewed by first establishing a perspective of air transportation accidents as a function of calendar year, geographic area, and phase of flight, and then by describing the threats to safety and NASA research underway in the three representative areas of engine operational problems, meteorological phenomena, and fire. Engine rotor burst protection, aircraft nacelle fire extinguishment, the aircraft-weather interface, severe weather wind shears and turbulence, clear air turbulence, and lightning

are among the topics covered. Fire impact management through fire resistant materials technology development is emphasized. 78/00/00 78N29054

UTTL: Spatial disorientation in general aviation accidents
AUTH: A/KIRKHAM, W. R.; B/COLLINS, W. E.; C/GRAPE, P. M.; D/SIMPSON, J. M.; E/WALLACE, T. F. CORP: Civil Aeromedical Inst., Oklahoma City, Okla.
ABS: Spatial disorientation (SD) refers to an incorrect self-appraisal of the attitude or motion of the pilot and his aircraft with respect to the earth. This paper defines elements of SD problems as encountered in general civil aviation. Accident reports made by the National Transportation Safety Board for a recent 6 year period were reviewed. Statistical computations were made relating SD to fatal accidents. SD was involved in 2.5 percent of all general aviation accidents, nonfatal and fatal. However, SD ranked as the third highest "cause" in fatal small fixed-wing aircraft accidents and is closely related to the second highest cause, continued VFR flight into adverse weather. Inclement weather was associated with 42 percent of all fatal accidents, and SD was a cause or factor in 35.6 percent of these cases. Fog (56.8 percent) and rain (41.8 percent) were the most prevalent adverse weather conditions. Non-instrument-related pilots were involved in 84.7 percent of SD weather-involved accidents. These and other data attest to the importance of this psychophysiological phenomenon (SD) in flight safety. Suggestions are made of ways to improve pilots' awareness and understanding of this problem.
RPT#: AD-A053230 FAA-AM-78-13 78/03/00 78N27755

UTTL: Disorientation training in FAA-certificated flight and ground schools: A survey
AUTH: A/COLLINS, W. E.; B/HASBROOK, A. H.; C/LENNON, A. O.; D/GAY, D. J. CORP: Civil Aeromedical Inst., Oklahoma City, Okla.
ABS: A voluntary questionnaire answered by 674 flight and ground schools provided information on (1) the conduct of formal instruction about disorientation; (2) the occurrence and content of lectures on disorientation; (3) use of on-the-ground demonstrations of disorientation; (4) use of in-the-air demonstrations of disorientation; (5) use of films on pilot vertigo; (6) amount of instrument flying training students receive; (7) amount of instrument flying training required of flight instructors to maintain their proficiency; (8) adequacy of the school's program on disorientation training; (9) other comments, and (10) numerical data regarding the number of students beginning and completing various flight and/or ground school courses. More than one-third of the respondents evaluated their disorientation training program as inadequate and defined the inadequacy most often as a lack of appropriate materials, aids, and information.
RPT#: AD-A047718/2 FAA-AM-77-24 77/09/00 78N19768

UTTL: The 1975 accident experience of civilian pilots with static physical defects
AUTH: A/DILLE, J. R.; B/BOOZE, C. F. CORP: Civil Aeromedical Inst., Oklahoma City, Okla.
ABS: The 1974 aircraft accident experience of civilian pilots with selected static physical defects was examined and reported previously. Conditions of blindness or absence of either eye, deficient color vision with a waiver, and deficient distant vision were present in significantly more accidents than were expected. Pilots with these conditions reported considerably higher median 6 month flight times than did an active airman population sample or accident airmen without selected pathology. Concern was raised about the failure to relate any of the accidents to the pilot's physical conditions. The 1975 accident data were examined, and the same three groups were found to have significantly more accidents. The reported recent and total flying times for all airmen with these defects were determined and accident rates were calculated. When the accident experience of airmen with any of these defects was compared with the active airman population accident experience, the rates for airmen with blindness or absence of an eye were still found to be significantly higher.
RPT#: AD-A045429 FAA-AM-77-20 77/08/00 78N12050

UTTL: General aviation pilot stall awareness training study
AUTH: A/HOFFMAN, W. C.; B/HOLLISTER, W. M. CORP: Aerospace Systems, Inc., Burlington, Mass.
ABS: Focus was placed on the potential of enhanced pilot training in the areas of stall/spin recognition, avoidance, and recovery. The objectives were to determine the weakness of present flight training syllabi, the methods of training used, and the flight instruction presently provided in the stall/spin area; conceive an experimental stall/spin increment to an established flight and ground training syllabus; and conduct flight and ground test evaluations of this syllabus change and the flight instruction techniques required. Volunteer student pilots were divided into four groups, each receiving different degrees of stall/spin training. Evaluation flight tests were

conducted prior to and after the training period. Results indicate that additional ground training in the subject of stalls and spins, additional flight training on stall awareness, and/or intentional spin training would all have a positive influence toward reducing inadvertent stalls and spins.

RPT#: AD-A041310/4 ASI-TR-76-37 FAA-RD-77-26 76/09/00 78N10705

UTTL: Statistical analysis of US Navy major aircraft accident rates, pilot and aircraft time-dependent variables

AUTH: A/RASHID, A. CORP: Naval Postgraduate School. Monterey, Calif.

ABS: Aircraft accident rates by month were analyzed for randomness, cyclic pattern or increasing/decreasing trends for all attack, fighter and propeller type aircrafts. The technique of Runs test was employed to the runs above and below the median. The analysis of pilot/aircraft time dependent variables was also done for both accident and non-accident pilots/aircrafts. The hypothesis tested was, the accidents per hundred pilots/aircrafts were the same for each category of pilot/aircraft variable. The chi square one sample test, the chi square test for K independent samples and the Mann-Whitney U test were used for the analysis. The aircrafts considered for the analysis of pilot variables were A-4, A-7 and F-4, and the aircraft considered for the analysis of aircraft variable was F-4.

RPT#: AD-A040096 77/03/00 77N30099

UTTL: Analysis of selected general aviation stall/spin accidents

UTH: A/SHRAGER, J. J. CORP: National Aviation Facilities Experimental Center, Atlantic City, N. J.

ABS: An automated data search of existing general aviation data bases was employed in an effort to relate aircraft stall/spin accident history to general design characteristics. The technique utilized a chi square analysis to evaluate a stall/spin history of selected aircraft. The statistical analysis indicated that accident rates are influenced by aircraft usage, and by pilot experience. Low horsepower, low stallspeed aircraft have a higher propensity to stall/soin accidents, the highest incidence being in the takeoff phase of flight.

RPT#: AD-A040824 FAA-NA-77-2 FAA-RD-77-41 77/04/00 77N29113

UTTL: Analysis of U. S. navy major aircraft accident rates by aircraft type

AUTH: A/JOHNSON, G. F. CORP: Naval Postgraduate School. Monterey, Calif.

ABS: An analysis of U.S. Navy major aircraft accidents during the period Fiscal Year 1972-1974 was conducted. Forward (stepwise) Multiple Regression techniques were employed on a group of ten basic variables considered time dependent. The multiple regression techniques were employed to develop predictive equations for the dependent variable, Accident Rate with a view to determining which of the basic variable measures were significant in accident rate studies and if the variables are unique to a specific aircraft community or generally applicable to all aircraft. Aircraft considered independently were A-4, A-6, A-7, and F-4, additionally composites of Attack aircraft (A-3, A-4, A-5, A-6, A-7), Fighter aircraft (F-4 and F-8), Propeller aircraft (E-1, E-2, C-1, C-2, S-2, P-3, C-117, C-118, and C-130) and Helicopters (H-1, H-2, H-3, H-46, and H-53) were considered.

RPT#: AD-A032379 76/09/00 77N22056

UTTL: Analysis of US Navy aircraft accident rates in major aviation commands

AUTH: A/BUCHER, L. C. CORP: Naval Postgraduate School. Monterey, Calif.

ABS: Time dependent variable measures were obtained for all major aircraft accidents between July 19[illegible] and July 1974. Using these time dependent variables and functional forms of these variables, a regression analysis was performed for each of eight major aviation commands. By using these functional forms of the variables, a relatively high amount of variance in aircraft accident rate was accounted for at a high confidence level in some commands. When reviewing the results of the eight major commands considered, it was particularly noted that the variables most instrumental in explaining the variance in aircraft accident rate were not all pilot oriented but were variables interpreted as being related either to pilot experience level, pilot proficiency or aircraft condition.

RPT#: AD-A031837 76/09/00 77N22055

UTTL: USAF pilot proficiency: An analysis of actual and simulated flight data

AUTH: A/ANDERSON, J. T.; B/PHILLIPS, J. F. CORP: Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. CSS: (School of Systems and Logistics.)

ABS: The purpose of this study was to determine whether USAF pilot proficiency has been reduced since the

implementation of energy conservation measures (1972). These conservation measures resulted in reduced actual flying and the increased use of flight simulators. A census of total flight hours, aircraft accidents, and simulator usage data was analyzed for a defined population of pilots using direct comparison, analysis of variance, and regression analysis techniques. Pilot improficiency (inverse of proficiency) was defined as the average cost per aircraft accident per given period of time. This cost was used to quantify pilot proficiency, and a prediction model was formulated to determine its level when given flight and simulator hour variables. Other variables, such as phase of flight, aircraft type, pilot-in-command/instructor pilot time, and major command assignment were examined in the tests of the research hypotheses. The conclusions given the data of the study are: (1) There has been a decrease in total flying proficiency, and (2) The decrease in proficiency can be attributed to reductions in actual flight hours and to increases in the use of flight simulators as a substitute for actual flight.

RPT#: AD-A032296 SLSR-20-76B 76/09/00 77N21850

UTTL: Factors involved in the variability of monthly major aircraft accident rates

AUTH: A/POOCK, G. K. CORP: Naval Postgraduate School, Monterey, Calif.

ABS: Results are presented showing the development of regression equations to help determine human and/or aircraft variables which appear to account for the variability in monthly major aircraft accident rates.

RPT#: AD-A031840 NPS-55PK76071 76/07/00 77N20059

UTTL: Midair collisions: Aeromedical considerations

AUTH: A/YODER, J. E.; B/MOSER, R., JR. CORP: School of Aerospace Medicine, Brooks AFB, Tex.

ABS: Midair collisions have become an increasingly important fraction of total aircraft accidents in recent years. Psychophysiologic factors which have a bearing on collision avoidance are discussed in greater detail in this revision of an earlier review.

RPT#: AD-A030001 SAM-REVIEW-4-76 SAM-TR-76-29 76/08/00 77N18122

UTTL: Helicopter sling load accident/incident survey: 1963 - 1974

AUTH: A/SHAUGHNESSY, J. D.; B/PARDUE, M. D. PAA: B/(Old Dominion Univ.) CORP: National Aeronautics and Space Administration, Langley Research Center, Hampton, Va.

ABS: During the period considered a mean of eleven accidents per year occurred and a mean of eleven persons were killed or seriously injured per year. Forty-one percent of the accidents occurred during hover, and 63 percent of the accidents had pilot error listed as a cause/factor. Many accidents involved pilots losing control of the helicopter or allowing a collision with obstructions to occur. There was a mean of 58 incidents each year and 51 percent of these occurred during cruise.

RPT#: NASA-TM-X-74007 77/03/00 77N18117

UTTL: Recent experiment/advances in aviation pathology

CORP: Advisory Group for Aerospace Research and Development, Paris (France). Presented at the Aerospace Med. Panel Specialists' Meeting, Copenhagen, 5-9 Apr. 1976

RPT#: AGARD-CP-190 ISBN-92-835-0184-5 AD-A036347 76/12/00 77N17710

UTTL: Study and design of flight data recording systems for military aircraft

AUTH: A/BAETZ, L. N. CORP: Naval Postgraduate School, Monterey, Calif.

ABS: Investigation of aircraft wreckage does not provide crash investigators with adequate information. Crash-protected flight recorder data is invaluable when determining accident cause factors. Inertial navigation systems provide an excellent source of highly accurate flight parameters. Nonvolatile solid state memory is available which can replace failure prone magnetic tape recording in flight recorder systems. Microprocessors are available with the capability of compressing flight data for solid state memory storage. Data compression trials indicate that a flight data recording system using microcomputer preprocessing and nonvolatile solid state memory is feasible.

RPT#: AD-A028862 76/06/00 77N17446

UTTL: Identification of critical failures and cost effective reliability improvement approacnes

AUTH: A/KOGLER, K. J. CORP: IIT Research Inst., Chicago, Ill.

ABS: This report represents the results of an analysis to identify safety critical items in Cargo, Utility and Attack helicopters. Included in the report is a detailed failure mode analysis which quantitatively identifies critical modes of failure (both hardware and human) whose occurrence (singly or in combination) can cause hazard in flight. The identified failure modes are ranked in terms of criticality. Improvement

recommendations are made and a method is developed to assess their cost effectiveness. Improvement recommendations are ranked in terms of cost effectiveness.

**RPT#:** AD-A028333 IITRI-E6338-FR DRSAV-TR-76-26 76/06/00
77N17022

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**14. Abstract**


The lectures reproduced in this publication cover two sub-areas:

- Significant technical background factors:
  A review of those aspects of aeronautical engineering, aviation medicine, physiology, human factors and pathology which are pertinent to accident causation and therefore require investigation.

- The accident investigation process:
  A description of procedures, techniques and problem areas of special interest in the process of conducting an aircraft accident investigation.

Although the scope of the Lecture Series is broad, the focus is on military aviation and on aviation medicine.

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